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SEISMIC REGIONALIZATION OF EASTERN SIBERIA AND ITS GEOLOGICAL AND GEOPHYSICAL FOUNDATIONS

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This report contains a description of the results of many years of complex seismogeological, seismic and geophysical studies of Eastern Siberia aimed at establishing a basis for mapping its seismic regionalization. The genetic classification of the residual seismogenic deformations of the earth's crust and the fundamentals of the paleoseismogeological method--determination of the location and intensity of powerful earthquakes--are presented. A study is made of the problems of predicting earthquakes, the seismic regionalization and the peculiarities of the manifestation of earthquakes under permafrost conditions.

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Annotation

[Text] A description is presented of the results of many years of complex seismogeological, seismic and geophysical studies of Eastern Siberia aimed at establishing a basis for mapping its seismic regionalization. The genetic classification of the residual seismogenic deformations of the earth's crust and the fundamentals of the paleoseismogeological method--determination of the location and intensity of powerful earthquakes--are presented. A study is made of the problems of predicting earthquakes, the seismic regionalization and the peculiarities of the manifestation of earthquakes under permafrost conditions.

The book is designed for a broad class of specialists in the fields of seismogeology, seismology, regional geophysics and engineering geology. It can be used by the design organizations.

Foreword

The latest official map of the seismic regionalization of Eastern Siberia was compiled in 1962 (V. Solonenko, 1963a, 1968a). Since that time broad data have been accumulated which directly or indirectly reveal the conditions of the manifestation of earthquakes in Eastern Siberia, primarily in its most seismically active part -- the Baykal rift zone.

In order to establish the geological and geophysical basis for the seismic regionalization, a comprehensive analysis was made of the seismological, geophysical and geological data. It demonstrated that it is far from always possible from this group of data to obtain a unique or close to actual estimate of the possible seismicity level of one region or another. Therefore in the proposed paper certain contradictions are unavoidable, the elimination of which will become possible after many years of instrument observations.

Moreover, the seismic events in 1962-1975 confirm the seismic regionalization map of 1962: it did not require theoretical reworking, that is, the effectiveness of the procedural principles on which it was based -- the joint analysis of the seismological, geophysical, seismogeological and paleoseismogeological data -- was confirmed.

This paper was written, on the one hand, as a section of the All-Union theme of Seismic Regionalization of the Territory of the USSR, and, on the other hand, as a development of the theme of Seismic Regionalization on Paleoseismogeological Principles,[1] which was entrusted to the Institute of the Earth's Crust by the State Committee of the Council of Ministers of the USSR on Science and Engineering in 1958. Accordingly, a special section has been set aside in the monograph on the paleoseismogeological method which must not be considered as an index of the basic role of this method in seismic regionalization. The objective solution of this complex problem is possible only on the basis of complex seismological, seismogeological and geophysical data not contradicting, but reinforcing each other. Therefore, not only seismogeologists, but also co-workers from all of the laboratories of the geophysics division of the Institute of the Earth's Crust participated in this work: the Seismogeology Division (V. P. Solonenko, S. D. Khil'ko, V. S. Khromovskikh, R. A. Kurushin, V. V. Nikolayev, M. G. Dem'yanovich, S. V. Lastochkin), Regional Seismicity (S. I. Golonetskiy), Seismology (V. M. Kochetkov, L. A. Misharina, A. V. Solonenko), Geophysical Studies of the Earth's Crust (Yu. A. Zorin, M. R.Novoselova), and Engineering Seismology (O. V. Pavlov, N. Ye. Zarubin). In addition to the mentioned reponsible executive agents, the work was also participated in by A. D. Abalakov, N. S. Borovik, K. I. Bukina, L. G. Yevstigneyeva, V. M. Zhilkin, L. R. Leont'yeva, G. Ye. Myl'nikova, F. A. Novomeyskaya, A. D. Sarapulov, R. M. Semenov, N. V. Solonenko, V. I. Tatarnikova, A. A. Tret'yak, Ye. V. Fomina and A. V. Chipizubov. The earthquake magnitudes were redetermined by V. V. Kislovskaya (the Institute of Earth Physics of the USSR Academy of Sciences).

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[1] Not only the seismic regionalization of Eastern Siberia on paleoseismogeological principles was investigated, but also a test of the applicability of the paleoseismogeological method under the conditions of compression of the earth's crust. The latter was done in the example of the Greater Caucasus where special studies were made in 1970-1972, the results of which are especially discussed.

CHAPTER I. SEISMOGENIC DEFORMATIONS AND THE PALEOSEISMOGEOLOGICAL METHOD

"Experience is the ultimate basis for knowing the world."

-- Roger Bacon. OPUS MAJUS

In practice, the most important result of seismological research is determination of the location and possible recurrence rate of powerful, especially maximal earthquakes.

The prediction of the exact time of an earthquake, its location and intensity could have inestimable significance. However, the solution of this problem, if it will ever in general be solved, is a matter of the indefinite future. An earthquake is a geological process. Based on the physics of earthquakes and on changes in the earth's crust in connection with them, that is, on the consequences of seismogenic processes and not the cause of them, without taking into account the noncommensurable nature of the geological and human time scales, it is possible easily to accept what one likes as reality.

The causes of strong earthquakes are in general unknown to us. It is possible to make assumptions about them which are more or less substantiated by the geophysical data. The system on which almost all seismological developments are based, the fracture-earthquake, is decapitated. In reality, this is only the consequence of deep processes which cause a stressed state in large volumes of the earth's crust or the tops of the upper mantle in the earth's crust, and discharge of the basic part (but not all) of the accumulated excess energy takes place by movement of the blocks of the earth's crust, primarily, the most contrasted, along the fractures but far from exclusively along them.

Seismostatisticalinstrument data widely used in recent years for various types of forecasts (the recurrence rate of earthquakes, seismic activity, maximum earthquakes, seismic vulnerability, and so on), having unquestioned high significance, frequently do not provide reliable solutions to the problems. Being objective from the beginning, when processing these data, in order to agree with macroseismic statistics, they must be subjected to subjective sorting (for example, aftershocks,groups, earthquake swarms, and so on must be excluded from the processing). Here, especially for the

highly active regions, it is usually impossible to say where the aftershocks end and the normal seismic regimen is established.

As to what the normal seismic regimen is--this is also unknown. It would be possible to use this term to refer to the combination of frequency and energy class of the earthquakes which would make it possible to obtain the true recurrence rate of powerful earthquakes and their maximum intensity on the recurrence rate graphs. However, for this purpose it is necessary to have reliable seismostatistical data available for the intracontinental seismic regions for no less than 500 to 600 years and even for the most seismically active zone, no less than 150 to 400 years.

Moreover, the complex paleoseismogeological and seismological studies in the Baykal rift zone demonstrated that the "normal" seismic regimen is only an episode in the activity of the specific seismogenic structure. It usually develops with respect to the following stages: 1) (nonmandatory) -- foreshocks; 2) powerful earthquakes; 3) active seismic activity (aftershocks); 4) decrease in seismic activity; 5) prolonged (a minimum of ten and sometimes hundreds of years) calm; 6) degeneration of seismic activity; 7) short-term (years, perhaps the first decades) calm; 8) first or second stages again.

The "normal" seismic regimen is possible only for part of the time interval of the sixth stage, and the duration of the stages (with the exception of the second, short-term one) is known only approximately or it is unknown. Therefore the determination of the recurrence rate of powerful earthquakes, to say nothing of their upper level, by the short-term instrument observations for specific seismogenic morphostructures is a hopeless matter.[1] If for the regions with significant seismostatistical data for hundreds of years, and even for one or two thousand years the seismological methods can give a more or less correct estimate of the practically important seismicity parameters, in order to estimate the seismic danger of previously uninhabited and seismically (instrumentwise) uninvestigated territories, the seismogeological methods are the most important. The history of their development is prolonged, but we cannot dwell on it here.

The most popular at the present time are the historical-structural method (Gorshkov, 1949; Belousov, 1954; Petrushevskiy, 1955, 1957), seismotectonic (Gubin, 1950, 1953, 1960), tectonophysical (Gzovskiy, 1957, 1963; Gzovskiy, et al., 1958, 1960, 1973) and paleoseismogeological methods (Florensov, 1960b; Solonenko, V., 1959, 1962b, 1963a, b, 1966, 1970a, b, 1973 a-c). Each of these areas is a component part of a united seismogeological or, more correctly, geological and geophysical method of

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[1]In a significant seismogenic zone with respect to area (tens to hundreds of thousands of square kilometers) with many more or less like seismogenic morphostructures, naturally averaging of the seismic regimen takes place, and by the recurrence rate graphs it is possible to obtain a more or less correct idea of the recurrence rate of the powerful earthquakes (but not their upper level) for the zone as a whole.

predicting the location, intensity and recurrence rate of powerful earthquakes, and each has its advantages and disadvantages.

The historical-structural method which is fruitful when analyzing the global or regional laws of seismic manifestations during seismic regionalization frequently encounters insurmountable difficulties, which one of the founders of the method notes: "During the experiments clearly defined restrictions were discovered with respect to the possibilities of the historical-structural analysis for purposes of seismic regionalization. It was established that it is possible to find relations between seismicity and geological peculiarities only in a generalized form" (Petrushevskiy, 1976, p 69).

The possibilities of the seismotectonic method are essentially limited to seismostatistics. In order to forecast the force of the shocks, "extrapolation of the recorded seismicity from one zone to another, neighboring, like zone" is required (Gubin, 1971, p 11). For proper estimation of the maximum possible earthquake intensity, reliable seismostatistical data are needed for hundreds of years. The latest studies (partially using the paeloseismogeological method) indicate that for a specific seismically dangerous area, even in the most seismically active zones, a long time is needed to accumulate the energy for earthquakes of the highest force for these zones, 110 years at Muroto, 140 years at Kanto (Sassa, 1951; Sigimura, 1968), 150 years in the Anatolian fault zone (Ambraseys, 1970), 400 years in Alaska (Hansen, et al., 1966; Plafker, 1968). The information for these time intervals (they must, of course, be taken as average, provisional data) can be obtained only for individual ancient cultural centers, and at that with significant gaps during the social-political upheavals, pandemics and other disasters, and they do not encompass the uninhabited or sparsely inhabited areas, they are meager for the territories where religious prejudices prevented the accumulation of data (for example, in the lands of the Buddhist-Machayanalamaists).

The tectonophysical method initially was of interest in that it offered the possibility of predicting earthquakes or narrowly local zones. One of the most important elements of the method -- analysis of the quantitative expression of vertical movements of the earth's crust -- originally gave hopeful results (Gzovskiy, et al., 1958), but on being used in adjacent regions, serious difficulties occurred (Gzovskiy, et al., 1960), and when trying to use it to explain the regional seismicity, the author (Gzovskiy, 1963) came into contradiction with the actual data (Florensov, et al.,1964).

On accumulation of data by repeated geodetic observations and the results of a detailed structural analysis of the seismic dislocations, it was discovered more and more clearly that the signs of vertical and horizontal movements of the earth's crust in the active areas frequently change (Solonenko, V., 1973a). In Japan at Cape Muroto, the history of sudden uplifts during disastrous earthquakes and systematic subsidences between them has been traced for several centuries. In Alaska, between disastrous

earthquakes subsidence of up to 11 mm per year takes place, and the instantaneous heaving during the earthquake not only has compensated for this subsidence, but in the last 2500 years it has resulted in uplift at an average rate on the order of 10 mm/year (Plafker, 1968).

It is no accident that in their latest paper, M. V. Gzovskiy and A. A. Nikonov (1973) give a very careful estimate of the possibilities of determining the seismicity levels with respect to the rates and the gradients of the rates of movement -- the most important function of the tectonophysical method: "The relations of seismicity to tectonic movements reflect only the most general statistical laws, and they cannot be sufficient for engineering estimates of seismic danger" (p 54). The effort to improve the method as a result of using data on mountain shocks and the isolation of four types of movements with respect to seismicity does not change the situation. The stresses causing mountain and seismic shocks cannot have a functional relation -- their nature is entirely different. The types of movements, judging by the direction of the effective external active forces indicated on the diagrams in the quoted article (Gzovskiy, Nikonov, 1973, p 5) are a few of the possible ones in nature, and the fourth type of movement -- teleseismic -- which can cause an earthquake tens and hundreds of kilometers from the point of seismogenic movement appears quite doubtful.[1]

Detailed seismogeological studies in areas where it is possible to compile a history of the development of the latest geological processes, for example, active tectonics in the latest volcanism (ACTIVE TECTONICS..., 1966) or to discover the migration of modern tectonic processes (SEISMOTECTONICS..., 1968) indicate that the geodynamic fields changed significantly already in the Holocene. At the same time, estimation of the possible seismic activity without discovering the evolution of the seismotectonic processes with respect to rates and gradients of movements generalizing the results of the movements of the earth's crust at least for the Neogene-Quaternary time (29 million to 30 million years) appears to be less and less substantiated.

After the first enthusiasm for the method, on discovery of its obvious deficiencies, many specialists in the field of seismic regionalization have been inclined to reject it decisively as was previously done. However, under defined conditions the method can be used successfully to compare the expected level of seismic activity and probable recurrence rate of earthquakes in individual areas of the seismogeologically united zone with stable seismotectonic conditions, sometimes for a qualitative comparison of the potential activity of the adjacent areas and for the solution of other problems. However, it does not follow to expect more from this

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[1]The authors even present specific examples of three such earthquakes in the Garmskaya and the Northern Tyan'-shan' zones, which can only arouse suspicion: in such highly seismic zones, using the data over a large area, if desired, it is possible to establish the most improbable "correlations."

method than it can give. It is no accident that K. R. Allen, P. S. Amand, C. F. Richter and D. M. Nordquist, undertaking 29 years of seismogeological and seismological studies in Southern California, arrived at analogous conclusions to ours with respect to estimating the rates of vertical displacements for isolation of the active structures: "It is much simpler and more realistic to map the faults themselves than to try to calculate the rates of vertical displacement in the geological past or to measure such displacem nts at the present time" (Allen, et al., 1965).

The conclusions of this representative group of American seismologists and seismogeologists with respect to estimating the significance of the fracture tectonics for determining the seismic potential also agree with ours: "The most i portant problem remains the problem of whether the zones of high relief deformation ... can be predicted only on the basis of the locations of the 'active' fault zones... The answer remains emphatically 'yes': in fact, all of the basic seismic activity was concentrated in the areas of abundant formation of faults in the Quaternary period."

Thus, all of the enumerated seismogeological methods failed to offer the possibility of estimating seismic danger of previously uninvestigated regions, determination of the upper level of the seismic activity of specific seismogenic structures, obtaining data on the location of the epicentral zones and the recurrence rate of the most powerful earthquakes and also evolution of the seismicity of the specific areas. This gap is essentially filled by the paleoseismogeological method.

The paleoseismogeological method was the logical result of studying the neotectonics, seismogeology and geological consequences of strong (force 9 and higher, M≥6.5) earthquakes. The necessity for estimating the seismic danger of uninhabited or sparsely populated territories of Eastern Siberia for which there were no seismostatic data served as the direct reason for its development.

The paleoseismogeological method was in practice used for the first time when correcting the mockup of the seismic regionalization map of Eastern Siberia compiled in 1956 at the Institute of Earth Physics. The mockup of the map did not differ theoretically from the seismic regionalization map of 1947-1951 compiled under the direction of G. P. Gorshkov, for, as before, it was compiled on the basis of the seismostatistical method.

Based on the data with respect to the latest tectonics, seismicity and the first information on paleoseismodislocations, N. A. Florensov, A. A. Treskov and V. P. Solonenko proposed an increase in the extent of the zone of high-force earthquakes by 900 km to the northeast and by 400 km to the west (Florensov, et al., 1960), and a new map was compiled in 1960 (Solonenko, V., et al., 1960b). The subsequent seismic events and broad special seismological, seismogeological and geophysical studies confirmed the objectiveness of the paleoseismogeological method.

The conviction of the seismologists and seismogeologists that the residual deformation of the earth's crust during strong earthquakes is a rare phenomenon and faults can reach the surface only in the case of shallow-focus earthquakes (then only in exceptional cases) prevented recognition of the paleoseismogeological method for a long time. However, the examination of powerful earthquakes (with $M \geq 6.5$) in various highly seismically active areas of the world reliably refuted this idea. Moreover, when studying the pleistoceismal zones of almost all very powerful and disastrous earthquakes with crustal centers, paleoseismodislocations were invariably discovered (see, for example, Solonenko, V., 1962b, 1963a, b, 1970a, b; ACTIVE TECTONICS..., 1966; SEISMOTECTONICS ..., 1968; Kopp, et al., 1964; Kuchay, 1971, 1972; Trifonov, 1971; Allen, et al., 1965; Ambraseys, et al. 1969; Buchstein, et al., 1967; Qureshi, Sadig, 1967; Plafker, et al., 1971; Natsay-Yum, et al., 1971; Tchalenko, et al., 1974a, b; and so on).

The residual deformations of the earth's crust and the ground are varied. They are deeply interrelated, but for convenience of discussing the material and using them with respect to the degree of relation to the seismic process, we subdivided the residual deformations into seismotectonic, gravitational-seismotectonic and seismogravitational (Solonenko, 1972a, b; Solonenko, V., 1972, b, 1973a-c).

The seismotectonic deformations are connected with the tectonic movements of the earth's crust. With respect to their genetic attributes, encompassed area, morphostructural morphosculptural expressions, they are divided into regional, zonal and local.

Regional Seismogenic Deformations of the Earth's Crust

When examining the pleistoceism zones of disastrous earthquakes in the Mongolian-Baykal seismic belt, we arrived at the conclusion that the movements of the earth's crust are not limited to the zones next to the faults, but they encompass significant areas, at least, the sections of appearance of aftershocks (Solonenko, V., et al., 1969), and in the case of crustal centers, they can encompass areas up to tens of thousands and sometimes hundreds of thousands of square kilometers. The area S of the residual deformations of the earth's crust is approximately defined by the following formula as a function of the magnitude of the earthquake (M)[1]

$$\lg S = (0.99 \pm 0.07)\, M - 3.6 \qquad (1)$$

[1] The maximum value is for broad marine seismic areas encompassing the sea floor and the island archipelagos, and the minimum value, for narrow continenal seismic belts of activated platforms.

At the present time our concept of regional deformation of the earth's crust during powerful earthquakes has received instrument confirmation.

With respect to the mareographic and geodetic (repeated leveling and triangulation) data, for the Chilean earthquakes of 1960 (the principal shock on 22 May, M=8.4) vertical (to 3-5.7 meters) and horizontal movements of the earth's crust were established over an area of 130,000 km^2 (Plafker, Savage, 1970).

During the Alaskan earthquake of 27 March 1964 (M=8.6), the uplifts, subsidences and buckling of large blocks of the earth's crust took place over an area of about 300,000 km^2 -- (900-960)X(250-400 km) -- from the Aleutian Trench to the internal parts of the Alaskan ridge. The vertical displacements on the dry land were from -4 to +10 meters, and at the bottom of the sea to +15 meters or more; the horizontal displacements were up to 3 meters (Hansen, et al., 1966; Plafker, 1969).

It is possible that the movements of the earth's crust encompass still greater areas. A reason for this assumption can be the events which occurred in Transbaykal after the Muya earthquake. The first reports that water had appeared in the Toreya dry lacustral basins after the Muyskiy [Muya] earthquake were received in the fall of 1957 (before the Gobi-Altay earthquake). We did not attach any significance to this report, for the lakes are 750 to 800 km from the epicenter. However, the lakes quickly spread, and in 10 years the area reached 817.5 km^2 (the depth of lake Zun-Toreya reached .9 meters, Barun-Toreya, to 3.7 meters). The area of a number of lakes increased not only in the southern part of Transbaykal, but also in Northern Mongolia where a lake 16 km long appeared, and the area of the Khukh-Nur Lake increased by several times; the Uldzya River changed its direction and flowed from Mongolia to the USSR to the Toreya basins.

The majority of researchers of the years-long complex expedition studying this extraordinary event arrived at the conclusion that it is connected with the powerful earthquakes of 1957-1958 which occurred in Mongolia and the Baykal rift zone with M=6, 7.9, 8.6, 6.9, 7 and 6.5. "The movements (of the earth's crust) are of a differentiated nature, for the scale of the subsidences in the various lacustrine basins is different" (Marinov, 1973, p 79).

The enormous epicentral distances, of course, provide a basis for doubting the relation of such significant movements of the earth's crust, but exact coincidence of them in time with the powerful earthquakes in Mongolia and the Baykal rift zone and the absence of any relation to the other causes at least force the question to be stated of the possibility of movements of the earth's crust over areas on the order of a million square kilometers. Is this not the cause of the solidarity of the powerful earthquakes in the Mongolian-Baykal seismic belt (Solonenko, V., 1974)?

Mongolian People's Republic		Baykal Rift Zone
Kyakhta 6 February 1957, M=6	→	Muya, 27/June 1957, M=7.9 →
Gobi-Altay 4 December 1957, M=8.6	→	Nyukzha 5 January 1958, M=6.5 →
Bayan-Tsaganskoye 7 April 1958, M=7	→	Olekma 14 September 1958, M=6.5
Mogodskoye 5 January 1967, M=7-3/4	→	Tas-Yuryakhskoye 18 January 1957 M=7.

Until recently the regional seismogenic movements of the earth's crust were not used to discover the disastrous aspects of the past, although efforts were made to explain the formation of terraces by them (Plafker, 1968; Sigimura, 1968). However, when expanding the areas encompassed by the seismogeological studies there is such a possibility, especially in the marine seismic regions.

Inasmuch as the movements of the earth's crust frequently have different amplitude and sign next to each other, they can introduce significant disturbances into the normal evolutionary series of the relief. The simultaneous variation in relief of different types (transgressive and regressive) can indicate its seismogenic nature. The problem still lies in exact dating of these changes.

The zonal seismogenic deformations are movements of seismogenic morphostructures. A classical example of them is the displacement of the mountain group of Gurban-Bogdo of Gobi Altay during the earthquake of 4 December 1957 (force 12, M=8.6, center depth 18 ± 8, most probable 22-25 km). For the first time in the history of seismogeology the possibility was offered to study the movement during the course of the earthquake of a large morphostructure in a "closed system" at the same time as the seismogenic structures of other strong earthquakes either are highly complex or they do not have clear boundaries, and most frequently they are covered with sea and ocean water.

During the Gobi-Altay earthquake the mountain massif (275X30 km, absolute altitude to 4,000 meters), similarly to an icebreaker during lateral compression of the ice, rose and shifted to the east (the apparent amplitudes of the displacements to 10 and 8.8 meters; true, as a result of bending deformations, appreciably lower). Many explicit and latent elements of the mechanism of deformation of the morphostructure and seismogenic morphosculptures of the Gobi Altay appeared (Solonenko, V., 1959, 1960a, 1963a; Solonenko, V., et al., 1968; Solonenko, 1965, 1966).

A system of faults and other residual deformations of the earth's crust was formed with an overall length of about 850 km. All of the known and some of the previously unknown types of dislocations in the structural geology occurred: gravitational-seismotectonic wedge with vertical displacement amplitude to 328 meters, stripping of the mountain peaks, and so on.

During the Muya earthquake on 27 June 1957 (force 10-11, M=7.9, the depth of center 22 km) two seismogenic morphostructures were shifted: the Namarakit embryonic depression of the Baykal type and the fault-block uplift of the Udokan and southern Muya ridges. During the earthquake, the basin dropped 5 to 6 meters and was shifted to the southwest; the Udokan ridge shifted in the opposite direction 1 to 1.2 meters, and it uplifted 1 to 1.5 meters, and it was simultaneously overthrust on the depression with respect to the strike-slip thrust fault. The visible movement along the faults occurred over an extent of 140 km (90 km to the east and 50 km to the west of the instrumentally determined epicenter), and the extent of the Muya system of the fault itself connected with the earthquake of 27 June 1957, 35 km. Oscillations of the walls of the old faults occurred over the remaining extent (Solonenko, V., 1965).

The principal residual deformations for this type of seismogenic morphostructures are concentrated within the limits of the most active part of the morphostructural system -- in the embryonic depression, and in the less actively developed fault-block uplifts they are concentrated in the zone of faults delimiting them on the depression side (Solonenko, V., 1965; ACTIVE TECTONICS ...., 1966).

The presented examples of the zonal dislocations indicate that when discovering their paleoseismogenic analogs it is necessary first of all for the geologist to dismiss the canonical postulates of the handbooks on structural analysis. For example, a reliable sign of different age of the structures is considered to be geodynamic difference in type. In reality, during disastrous earthquakes any type of structure occurs simultaneously. The incompatible deformations are mutually transitional: for example, an overthrust can quickly turn into a powerful tensile fracture or fault (Solonenko, V., 1960a, 1963b).

In the case of paleoseismogeological reconstructions of powerful zonal seismotectonic phenomena, one of the knotty problems is stratification of the zonal deformations which will permit determination of the recurrence rate of strong earthquakes, the "viability" of the seismogenic structure, and so on. For this purpose, geological, historical-archaelogical, dendrochronological and radiocarbon methods can be used.

The local seismotectonic deformations are direct signs of the residual tectonic deformations of the earth's crust in the epicentral zones of powerful earthquakes. With respect to scale, type and structure of residual deformations which are visible on the earth's surface, the formation of which is not explainable by any other causes except seismic, the location and intensity of the earthquake, preseismostatistical for the given region, is determined.

The first standard scale for determining the intensity of an earthquake was established empirically (Solonenko, V., 1962a) when studying the powerful and disastrous earthquakes in the Mongolian Baykal seismic belt.

Then, with the accumulation of data on modern seismodislocations, it became possible to give a general formula for the approximate calculation of the magnitude of the earthquake with respect to the extent (I) of the seismodislocation zone:

$$\lg L_{km} = (1.01 \pm 0.02)\, M - 6.18.^{1}$$

The scale of the seismodislocations depends not only on the magnitude and the intensity of the earthquakes, but also on their depth and mechanism of the center, the geological structure of the epicentral zone and otner causes, as a result of which it can be different for earthquakes with identical energy characteristic.

The extent of the zones of seismogenic faults formed during modern earthquakes fluctuates from hundreds of meters (for M≥8.5). The maximum established amplitude of vertical displacement is from tens of centimeters to 10 to 12 meters, sometimes more, and horizontal displacement, to 8.85 meters.

When studying the paleoseismodislocations, it has been necessary more than once to deal with significantly greater amplitudes of the displacements by comparison with the ones observed in the epicentral zones of modern earthquakes which can be explained differently, but two cases are most probable.

1. Paleoseismodislocation has occurred not in the case of one but in the case of several earthquakes that have taken place close together in time, and it expresses the total effect of the displacements.

2. After the main shock, the movement of the walls of the fault continues during the aftershock activity and, possibly, even after that.

If the seismodislocation is represented by a seismotectonic scarp, when determining the amplitude of the displacement it is necessary to be especially careful, for on steep slopes the covering deposits or part of the old fault breaks away, and the clastic material can be absorbed by the fracture at the foot of the scarp. The illusion is created of a very large vertical displacement.

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[1] The correction factor of ± 0.02 is of geological significance. It is equal to 0 for faults, strike-slip faults, strike-slip thrust faults (with a subordinate shift component), maximal for shifts, minimal for upthrow faults and seismic zones with special types of stresses (for near vertical position of the major axis of the stress ellipsoid). If the shift component for the walls of the fault is simultaneously directed in opposite directions, then this prevents the development of faults, and their magnitude turns out to be less than usual (within the limits of up to twice as much with equal magnitude of the differently directed shifts).

In the case of block type seismogenic structures the area of the displaced sections bounded by the faults reaches 250 to 300 km^2.

Part of the seismologists and geologists still adhere to the old idea that the seismogenic fracture deformations encompass only the cover beds, although this also contradicts numerous known facts. There is actually little data on the behavior of seismodislocations at depth, but the existing observations more indicate an increase in displacement amplitudes with depth and not damping of the displacements. Thus, in the case of the Idzu earthquake on 25(26) November 1930 (M=7) a shift with an amplitude of 0.7 meters took place on the surface, and at a depth of 160 meters (in a tunnel on the Tokyo-Kobde railroad) it became a strike-slip fault with horizontal displacement of 2.4 meters and vertical displacement of 0.6 meters.

In the case of the Gobi-Altay earthquake where it was possible to study the shift surfaces in the cover rock and bed rock, the amplitude of the residual deformations apparent in the surface horizons turned out to be half or less than half the true displacement amplitude at depth.

The fact of prolonged existence on the steep slopes of the rock of the seismotectonic trenches is an index of deep occurrence of the joints. Only in the case of constant absorption of the clastic material by the joints is it possible for them to remain in the relief (see below).

We have already given attention (Solonenko, V., 1973a) to the hypertrophy of seismodislocations at the bottoms and on the underwater slopes of large bodies of water. For example, during the Kanto earthquake on 1 September 1923, the relative displacements of the bottom of the Bay of Sagimi reached -400 and +250 meters, and within the limits of up to 1170 meters (to -720 and +450)[1] although in the case of like earthquakes (M=8.3) on the dry land, the scale of the displacement does not exceed the first tens of meters and only rare structures of special type -- gravitational-seismotectonic wedges (see below) -- approach the subaqual deformations with respect to their amplitude.

In the case of the force 10 Central Baykal earthquake on 29(30) August 1959, the bottom of Baykal dropped 10 to 15 meters (Solonenko, V., Treskov, 1960), and on the dry land in the Baykal region the same earthquakes (M=6 3/4) caused displacements along the faults of a total of 0.8 to 1.2 meters.

The efforts to classify these phenomena as the result of consolidation of sediments are connected with lack of knowledge of the physical-mechanical

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[1]After the earthquake, four special ships worked in the bay. They took more than 86,000 measurements.

properties of the bottom soil which at a depth of several meters, as a rule, has negligible excess porosity, to say nothing of the fact that the rise of the sea or ocean floor in general does not leave room for such explanations (we are not talking about bottom deformations connected with underwater slides -- they basically are well recognized on the sonar recordings).

This phenomenon remains a mystery.

Gravitational-Seismotectonic Deformations

The movement of the walls of the faults during earthquakes frequently creates favorable conditions for movement of the rock masses under the effect of gravity.

The gravitational-seismotectonic structures are directly connected with the active seismogenic faults, but sometimes also with large fractures experiencing passive opening during the oscillatory movements of the earth's crust during strong earthquakes. The length of the known gravitational-seismotectonic structures reaches 7 km, for example, the structure of Shartlay (Solonenko, V., 1962b; SEISMOTECTONICS..., 1968, pp 25-28), an area up to 10 to 20 square kilometers.

At this time landslips or creep faults, gravitational-seismotectonic wedges and in one case, supposedly, rupturing of a ridge slope are known.

Landslip faults are formed on the steep slopes of mountains with high energy of relief, especially where the faults cut off the spurs of the mountains. The development of these faults is promoted by a combination of two systems of fractures: steep rear faults and more gently sloping weakened zones inclined in the direction of the foot of the slope. Under such conditions, even with small shoves of the blocks along the faults, the rear fracture at the crust expands sharply, and as a result of the steepness of the slope, the impression of significant vertical displacement is created. For example, in the landslip fault of the Snezhnaya seismogenic structure, the apparent amplitude of the vertical displacement is 25 to 90 meters, the width of the fault trenches is 35 to 90 meters, although the true mean-maximal amplitudes with respect to the fault are 7 meters. In some landslip faults there are 5 to 6 series of separation joints, and the landslip fault has a step structure (Khromovskikh, 1965, pp 15-64; Solonenko, V., 1964a, pp 179-180; SEISMOTECTONICS..., 1968, p 47-50).

The apparent amplitude of a landslip fault joint downslope decreases, the landslip fault scarp wedges out toward the thalweg and has the appearance of whiskers facing front on. However, sometimes the fault intersects the thalweg and the next cape, at the same time exhibiting its tectonic and not gravitational nature (Fig 1). Sometimes a true fault, emerging on the slope of a canyon, becomes a landslip fault.

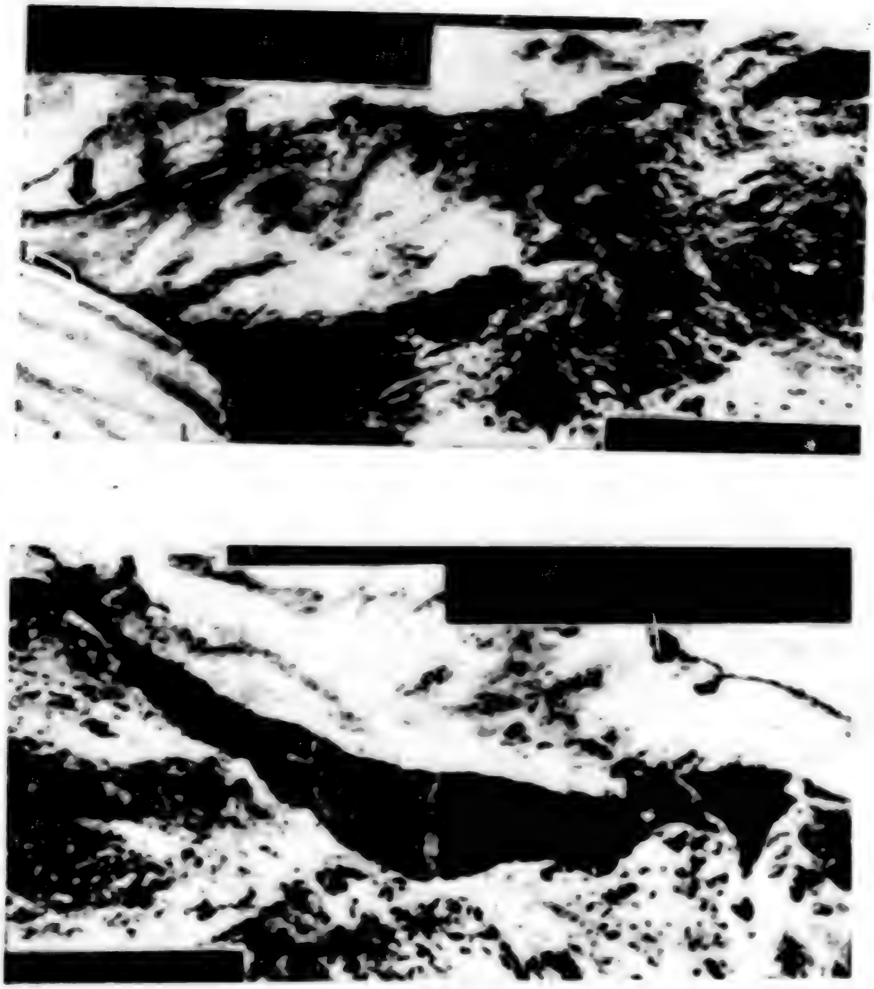

Figure 1. Seismogravitational or Gravitational-Seismic Tectonic Structure of Akiba (the Greater Caucasus), photograph by V. M. Zhilkin

During force 11 and 12 earthquakes, sometimes gravitational-seismotectonic structures of a special type are formed, the possibility for practical instantaneous formation of which has not been suspected previously by anyone. These include the gravitational-seismotectonic wedges and ruptures of the mountain slopes.

The gravitational-seismotectonic wedge combining the elements of tectonic subsidence and collapse was established for the first time in the central part of the pleistoceism region of the Gobi-Altay earthquake. Its location was predetermined by a cluster of ancient, new and latest faults, including three enormous fractures connected with recent earthquakes. In addition, it is located at the intersection of two large local faults and is associated with the north corner of the seismogenic central graben of Ikhe-Bogdo (10X15 km) formed on 4 December 1957.

During the earthquake against a background of general uplift, the corner of the joints opened up and part of the mountain (3754 meters high) made up of granitized shales 1.1X3 km in area collapsed into the earth. The amplitude of the vertical displacement of the tectonic wedge from east to west increased from 156 to 328 meters (the precision of the determination was from ±0.2 to ±2 meters). As a result of the wedging of force on the free side of the Bitut canyon, along the front of the wedge extrusion of wedges of the rocky ground took place upward to 60 meters and the formation of an overthrust-seismocupola frontal system took place (Solonenko, V., 1963b; Solonenko, 1965).

This phenomenon was so extraordinary that some of the geologists are still trying to question the possibility of the formation of such a seismotectonic displacement of a small block of the earth's crust and consider that an extraordinary cave-in took place here. A detailed aerovisual, ground and photogrammetric study (by the aerial photographs of the section made before and after the earthquake) leaves no room for such doubt. The disappearance of approximately half of the volume of the displaced block into the earth, the formation of milonites along the frontal displacer, and before them, the ascending seismocupola structures and overthrusts, the make-up of the body of the structure from monolithic rather than crumpled rock, reliably indicate the seismotectonic nature of the Bitut structure. It is sufficient for a nonprejudiced geologist to look at a photograph of the Bitut structure (Fig 2) made during its prolonged formation (3 January 1958) during the aftershocks to understand that it is not possible to talk about an ordinary cave-in here.

The rectilinear faults on the frontal part of the structure are well visible in the photograph. Later (in September 1958) during field documentation we established that these faults dip steeply into the depths of the slope and are covered with tectonic clay -- milonites formed during the earthquake (Solonenko, V., 1963b; Solonenko, 1965). It is clear that the formation and preservation of such faults in the cave-in is unconditionally included. The mechanism of the seismogenic collapses indicates this: during powerful earthquakes seismoexcitation of the crumbling mass takes place, and it goes at enormous speed to distances that are unobtainable in gravitational collapses (Solonenko, V., 1970a, 1972a, b; Plafker, et al., 1971; Solonenko, 1972a, b), which did not happen in Bitut although the conditions were more than favorable for this.

For subsidence of the tectonic wedge at Bitut, total opening of the fractures bounding it to 12 m was necessary, and the apparent (residual) width of the fractures in the epicentral zone reached 19 meters.

Later this type of structure was established in the Baykal seismic belt (Solonenko, V, 1962b; ACTIVE TECTONICS..., 1966; SEISMOTECTONICS..., 1968). The largest of them, the Shartlay structure on the west shore of Baykal is more than twice the size of the Bitut structure (length 7 km, width more than 2 km, vertical displacement amplitude to 880 meters).

The amphitheater of the structure turned toward the lake cut into the Baykal ridge beyond the Leno-Baykal divide line.

Recently the gravitational-seismotectonic wedges have begun to be found not only in the Mongolian-Baykal seismic belt but also in other highly seismic zones. For example, V. S. Federenko (1968) considers damming of Lake Sarychlek on the Chatkal'skiy ridge of Western Tyan'-shan by a seismogravitational structure of the Bitut type probable. It is possible that this type of structure occurred on the Yenisey 6 km above the dam of the Sayano-Shushenskaya hydroelectric powerplant. It encompassed both shores and the channel of the river where its local increase in depth by 90 meters has been established.

Genetically the mountain graben-troughing (subsidence) of the mountain tops established in the Stanovoy Highland (Solonenko, V., 1962b; ACTIVE TECTONICS..., 1966), in the Baykal region [Pribaykal'ya] (Khromovskikh, 1965), and in the Caucasus (Khromovskikh, et al., 1972; Solonenko, V., Khromovskikh, 1974 -- structures of Lebskaldi Tseri) are close to the gravitational-seismotectonic wedges.

A characteristic and obviously rare type of gravitational-seismotectonic structure is the punctures of the mountain slopes. Such a phenomenon has still been established only at one point -- north slope of the Southern Muya ridge. Here the ridge in the form of an arc is advanced into the Muya rift basin. A slip-strike thrust fault runs along the slope of the ridge, forming the chord of this arc at the same time as the frontal fault (strike-slip?) bounds it along the border of the ridge and the basin.

The primary cause of the formation of the structure is assumed to be a strike-slip thrust fault occurring during an earthquake with an intensity on the order of force 11 ($M = 7$-$3/4$). Here the seismic acceleration exceeded the gravitational acceleration which caused powerful stresses in the rock massif advanced into the basin, and a sharp shift fractured it along the surface inclined in the direction of the basin at an angle of 5°. The maximum horizontal shift reached 170 meters. A rupture 6 km long, triangular in cross section, with an average width at the base of 300 meters and height along the rear fracture of about 200 meters occurred on the slope. The volume of the rupture was on the order of 450 million m^3.

The structure, although documented (ACTIVE TECTONICS..., 1966), under the conditions of its formation leaves much unexplained, and it awaits additional, more detailed studies.

With respect to the mechanism of formation, the structure obviously is similar to the shearing of the tops of the mountains -- the transitional form from the gravitational-seismotectonic to seismogravitational deformations.

Figure 2. Bitut Structure. Photo by N. A. Florensov.
a -- rear fault, ampl'tude to 328 ± 2 meters, dip to the south at an angle of 70°; b -- faults on the frontal section of the structure dip to the north at an angle of 70°.

In the case of disastrous earthquakes, especially in mountainous areas, often the greater part of the human victims and material losses are connected not with the earthquakes themselves, but with accompanying seismogravitational phenomena.

The earthquake on 16 December 1960 in China (force 12, M=8.6) killed 200,000 people; of them, no less than 180,000 died in landslips, avalanches and earth flows.

During the earthquake of 10 July 1949 in the mountains of Tyan'-Shan' (force 10, M=7.5) the rayon center of Khait was destroyed in a landslip, and the seismogenic avalanches and flows were carried up to 20 km along the valleys, destroying dozens of populated places and fertile lands.

In May 1960 (M to 8.4-8.6) the Chilean earthquake caused thousands of slides and landslips, in part accompanied by the formation of new lakes, the destruction of old ones, mud flows causing great material losses and loss of many lives (Tazieff, 1960; Davison, Karzubovic, 1963; Weischet, 1963; and so on).

During the Alaskan earthquake of 27 March 1964 (M=8.6) the greatest material losses were caused by slides, and loss of lives by tsunami (Hansen, et al., 1966).

The Peruvian earthquake of 31 May 1970 (M=7.7) came sadly to be known as the Guaskaran landslip. The city of Jungey and part of the city of Ranrahirka with 18,000 people -- 40% of the victims and destruction of the earthquake -- were buried under the landslip mass (THE PERU..., 1970). The greater part of the remaining dead were victims of landslips, slides and mudflows (Plafker, et al., 1971).

The epicenters of the Chilean, Alaskan and Peruvian earthquakes were in the Pacific Ocean, and on the dry land their intensity decreased significantly. Therefore the victims and losses connected with the seismic effect itself amount to a total of 10 to 20% of the total losses, and with seismogravitational phenomena, 80 to 90%.

However, not only are such unique seismic disasters dangerous for man and nature. The "routine" powerful earthquakes encompassing areas many times smaller are repeated hundreds of times more frequently, and their total destructive effect is comparable. Thus, for example, during the earthquake in New Guinea in 1933 (M=6.1), landslips encompassed 240 km^2. The vegetation and soil layer were completely strippedover an area of 60 km^2. According to the calculations (Pain, Bowlar, 1973), 60 to 70% of the total denudation layer was removed by earthquakes.

The presented examples (a few of the known examples) indicate how vitally important seismogeological engineering forecasting is. Even if the time of the earthquake were known, the settlements would still be destroyed,

and the majority of the people would die, but not in their homes, but in areas where they would look for safety. Therefore engineering seismogeology which is only in its infancy must join the ranks of the most important branches of knowledge called on to come to the defense of the society and its achievements against earthquakes.

The seismogravitational phenomena themselves are varied and mutually overlapping: settling and subsidence of mountainsides, landslips, slides, avalanches and dirt flows, mudflows, and so on. They are known appreciably more widely than the first two types of seismogenic phenomena, for, first of all, they are encountered appreciably more frequently, they have been observed many times during earthquakes, and, secondly, for understanding of them the specialists do not need to cross the barrier of traditional concepts of the slowness of tectonic processes.

In order to discover the seismogenic nature of the gravitational phenomena, the identification of their age, discovery of the relation to seismogenic and seismocausative structures and the analysis of the dynamics of movement of the mountain masses have primary significance.

The simultaneousness of various shifts of the soil masses over a large area is a reliable sign of their seismogravitational nature. They are usually distinguishable from the gravitational phenomena connected with disastrous rains. The seismogravitational movements of mountain masses during disastrous earthquakes take place over an enormous area (of thousands of km^2): Muya, 1957, 150,000 km^2; Chile, 1960, more than 130; Alaska, 1964, 300; Peru, 1970, 65, and so on. Simultaneously, hundreds and thousands of landslips, slides, earth and mud flows are formed and so on. No other natural phenomenon can cause such enormous movements of soil with respect to size, amount and affected area.

In mountainous regions of modern orogeny, a significant part of the seismogravitational morphosculptures have to the present time been taken as exogenic (landslip glacial, proluvial and others). This is connected primarily with the fact that the seismoexcited landslips and avalanches and dirt flows follow an unusually long procedure, and the seismogravitational facies of the sediments are similar to glacial or proluvial.

The seismogravitational, destructive and accumlative and the corresponding exogenic morphosculptures in individual cases are often difficult to distinguish or indistinguishable. However, they have their own qualitative, quantitative and temporal peculiarities.

The tectonic stresses of the rocks, seismic accelerations and vibrations during earthquakes exciting the soil masses basically change the conditions of their stability and movement. Accordingly, the seismogravitational morphosculptures can develop under geomorphological conditions such that the formation of the analogous exogenic morphosculptures is impossible. The formation of them itself in the exogenic version requires a different, usually prolonged time -- up to many thousands of years -- and in the

seismogravitational version, in practice, it takes place instantaneously. The first in the region are of different age (stratified morphosculptural generations), and the second are simultaneous (discontinuous or imposed morphosculptural generations).

The change in stability of the mountain masses during earthquakes can arise from different causes. The most important of them are the following: 1) seismic accelerations and a decrease in strength of the rock; 2) a change in slope angle of the unstable planes; 3) thixotropic liquefaction of the soil.

Seismic accelerations are the cause of slides, landslips and other gravitational phenomena on the slopes. No one denies this, but there is no satisfactory mathematical model of the relation between the earthquake and the gravitational shift, and the possibility of solving this problem is still not foreseen. The calculations of the probable nature of the stresses occurring during the earthquakes on the slopes are being performed in a region considered to be linear (according to the calculated notes, the seismograms, accelograms, velocigrams), but the instruments record the oscillatory and not the true movements of the earth's crust. When examining disastrous earthquakes ($M>7\text{-}3/4$, $I_0>$force 10) wherever it is possible reliably to determine (by the slip surfaces, special types of seismogenic folded structures, and so on), it is discovered that the true movement is reciprocal (in the vertical and horizontal directions) with rotation. The rotational deforming movements are clearly manifested also in the force 8 zone of force 9 earthquakes (Solonenko, V., Treskov, 1960). In addition, for the calculations it is necessary to consider the depth of occurrence of the parting surface, the weight of the active and passive parts of the landslide-slip, the stress-rupture strength and the strength at the time of the tremor, the angle and direction of approach of the seismic waves, the duration of the tremor, the degree of flooding, the degree of stress relief or, on the contrary, the degree of preparation for shifting of the mountain masses by the preceding earthquakes and a number of other indexes, the majority of which are impossible to establish in practice, especially for a regional evaluation of landslide-slip danger.

A general idea of the effect of seismic accelerations can be obtained if we consider the seismic effect on the slope as an increase in its slope angle ($+\alpha°$):

I	M	m	$+\alpha°$
5	$4-4\frac{1}{2}$	12—25	0.5—1.5
6	$4\frac{1}{2}-4\frac{3}{4}$	25—50	1.5—3
7	$4\frac{3}{4}-5\frac{1}{2}$	50—100	3—6
8	$5\frac{1}{2}-6\frac{1}{2}$	100—200	6—12
9	$6\frac{1}{2}-7$	200—400	12—25
10	$7-7\frac{3}{4}$	400—800	25—38

where I is the force according to the MSK-64 scale; M is the magnitude for depths of centers of 15 ± 5 km; m is the seismic acceleration (cm/sec) for the periods of 0.1 to 0.5 sec (Medvedev, et al., 1965).

The presented figures indicate that under the corresponding conditions force 4 and 5 earthquakes can already be the cause of slides and landslips. Such cases are known. However, by long-term observations of slides in the Crimea it has been established that during the period of excess moisture, the force 4 earthquakes even cause slide activation at the same time as with a shortage of moisture they have not shifted for a force 8 earthquake (Glukhov, 1959).

It is much more reliable to determine the dangerous landslip zones by the seismostatistical and paleoseismogeological (Solonenko, V., 1962b, 1973a-c) data than by the mathematical models. The combination of these two methods offers the possibility of noting the boundaries of areas encompassed by the seismogravitational phenomena during earthquakes of defined intensity, determination of their types, dynamics, and so on characteristic for the given seismic region with its specific peculiarities of engineering seismogeology and manifestations of earthquakes.

The seismogravitational phenomena have mass development in the isoseismal areas of force 7-8 and higher. The total area in which it is possible to expect the development of seismogravitational phenomena coincides approximately with the total area of possible deformations of the earth's crust and is to a known degree subordinate to the above-presented relation (see p 8).

Variation of the Slope Angle of Unstable Planes

From the theory of slides and landslips it is known that on metastable slopes changes of the slope angles by tens of seconds are sufficient to disturb the equilibrium of the slope and for potential or stabilized slides and landslips to be put in motion.

One of the most reliable cases of such slides was described by Hadley (1964). During the Hebgen earthquake (M=7-3/4), depth of center 10-12 km, force 10; see Murphy, Brazee, 1964) a long stabilized slide was cut by a fault with an amplitude of 0.9 meters. As a result, the slope of the slide surface increased by 23 minutes. This disturbed the established equilibrium and 5 days after the earthquake the slide was set in motion.

A change in slope angle is possible for all types of seismotectonic deformations -- regional, zonal and local.

It is natural that the altered slopes are not sufficient with respect to the entire deformed area for the appearance of slides and landslips, but during regional forecasts this possibility must be considered. Obviously, part of the slides have taken place during the time of or soon after the Chilean earthquake (Tazieff, 1960; Weischet, 1963) and having no other apparent causes, were connected with the change in slope of the weakened planes in the mountain masses.

The zonal seismotectonic dislocations are accompanied by a significant number of different local seismotectonic deformations (faults, upthrow faults, grabens, strike-slip faults, and so on). Together, they rarely change the angles of slope of the weakened zones in an area to 10 to 20,000 square kilometers. However, the basic volume of unstable mountain masses here are fractured during the earthquake and its aftershocks as a result of seismic accelerations. If the seismic structure finds explicit geological reflection in the fault zone, then the most significant changes in slopes occur along this zone. In the case of powerful earthquakes, systems of seismodislocations occur in them, the approximate extent of which can be determined in the magnitude of expected earthquakes (see p 11).

Thixotropic Liquefaction of Soil

During an earthquake this phenomenon causes subsidence of the earth's surface, mud volcanoes, and slides. Numerous destructive slides of this type occurred during the Chilean and Alaskan earthquakes. In Alaska the damage in the cities of Seward, Valdez, Whittier, Anchorage, were reckoned in the hundreds of millions of dollars. The Ternahein slide encompassed the greater part of the city of Anchorage (Hansen, et al., 1966). When exploring the slope at the port later it was established that for the static position the slope here is completely stable.

The thixotropic liquefaction of the soil not only reduced the bearing capacity almost to zero, but also caused a powerful dynamic effect on the cover, frequently strong beds which broke out and shifted. Similar phenomena were observed on broad areas during the earthquakes in Mongolia (Khangayskiye on 9 and 23 July 1905, M=3.4 and 8.7; Gobi-Altay, 4 December 1957, M=3.6; Mogodskoye 5 January 1967, M=7-3/4).

It was proposed earlier that predominantly silty sand (true quicksand and pseudoquicksand) are predominantly capable of mass thixotropic liquefaction, but after the earthquakes in Chile, Alaska and Niigata (16 June 1964, M=7-1/2) it was discovered that often even sand and gravel, moraine and other similar soils liquefy.

When forecasting seismogenic slides of thixotropic rarefaction it is necessary to pay attention primarily to the coastal regions where earthquakes with an intensity of more than force 7 are possible.

The following main types of seismogenic slides and landslips can be noted.

1. Seismogenic stripping of mountain peaks was established for the first time in the pleistoceism zone of the Gobi-Altay earthquake. The stripping occurred as follows. During the earthquakes the amplitude of the displacement of the mountain massifs was more than twice the amplitude of the irreversible deformations (Solonenko, V., 1963a, pp 326-329). During the main shock the mountains shifted far to the east and above the position of equilibrium, and then they returned to the west and down so energetically

that they again passed the point of equilibrium, but in the opposite direction. The peaks of the mountains had greater amplitude of displacement than their base, as a result of which there was a lag of momentum of the peaks of the mountains behind their feet: when the base began the return movement, the peaks were still moving to the east, in connection with which powerful shearing forces occurred in them (Solonenko, V., 1968, 1963a; Solonenko, 1965, pp 345-348). The low angle of shear (a slope of 10 to 15° to the east) indicates that out of the two active forces, near horizontal seismoinertial and vertical gravitational, the former significantly exceeded the latter.

The cross sections of the cleavage planes were from 100 to 700X1500 meters, their occurrence was at a depth from tens to 350 meters. The peaks either shifted to the east with rotation counterclockwise or they were thrown into the canyon.

The shearing of the mountain peaks was established in southern Pribaykal'ye [Baykal region]. In the Snezhnaya seismic structure, the sharp pointed granite peaks were decapitated to 100 to 150 meters (base area 0.3X1.2 km), and the peaks were thrown into the canyon of the Snezhnoy River (Khromovskikh, 1965, pp 59 and 99).

2. Tectonic-Seismogenic Landslides and Landslips

In the modern orogenic belts, the overwhelming majority of enormous landslips and landslides are tied to the zones of seismoactive fractures and are directly or indirectly connected with earthquakes (Solonenko, V., 1950, 1972a, b; Churinov, 1964; Zolotarev, et al., 1968; Fedorenko, 1968; Solonenko, 1972a, b).

The seismotectonic movements of the earth's crust create instability of the rock masses, and their disastrous movements are caused, as a rule, by earthquakes. Not only are landslips and landslides formed, but new ones are prepared simultaneously.

The tectonic-seismogenic landslips develop predominantly as landslide-landslips Naturally, avalanching takes place after the most serious seismic oscillations, and the avalanching mass has extraordinary dynamics, including the range of its spread.

In the areas made up of moderately dislocated sedimentary or volcanogenic-sedimentary formations, in the presence of severe earthquakes, bands of beds up to several square kilometers in area slide (see Fig 1). Enormous cracks, benches up to tens of meters high in the form of seismotectonic scarps are formed, and a network of tectonic joints appears, and so on (Solonenko, V., 1973a-b; Solonenko, V., Khromovskikh, 1974).

3. Seismogenic Landslips with Seismically Excited Avalanche Mass

For the formation of such landslips obviously two conditions are necessary: instantaneous collapse and crushing of the rock and the effect of powerful

seismic oscillations on the plunging fine to medium lumpy mass, exciting it similarly to a vibration screen at the ore enrichment enterprises. The seismically excited avalanche mass moves at enormous velocity, it travels a path many times longer than ordinary, and it can cross broad valleys and rise high on the opposite slopes. There are facts indicating the possibility of such an avalanche mass crossing a canyon (Solonenko, Khromovskikh, 1974).

So far as is known, only one such landslips has been documented (Solonenko, V., 1978) in connection with the Khait earthquake on 10 July 1949 (force 10, M=7.5). The landslip in the Darikhauz Canyon (Fig 3) moved at a speed of about 100 km/hr, it crossed the Yarkhych River (Obikabud) and rose to a 15-meter terrace. The area of the landslip mass was 10.7 km^2, and the longest path was 10.5 km. In the case of an ordinary gravitational avalanche it did not exceed 1.5 to 2 km. A powerful air wave passed before the landslip. It swept away structures, broke off trees or tore them out by the roots and tossed them hundreds of meters through the air. A cascade profile is characteristic of such avalanches: the weakly inclined sections end in steep scarps (there are six large waves with the scarp height up to 50 to 60 meters in the Darikhauz Canyon). Soil spurts from the seismically excited mass, forming characteristic earth pyramids when it falls, and it squeezes the large rock monoliths into the shape of obelisks. With some planation which is unavoidable at times, the morphosculpture of the avalanche field could easily be taken as glacial.

Traces of the seismically excited avalanches have been established in various highly seismic regions. On the Zaaliyskiy ridge the seismogenic avalanches have traveled a path up to 30 km, they have departed 10 to 15 km from the foot of the mountains, they have crossed an intermontane basin and rolled up the slope of a ridge. The avalance mass which was previously taken as glacial deposits covered an area of up to 150 km^2 (Kurdyukov, 1964). Obviously, the Saidmarreh landslip (Iran) -- one of the largest in the world with a volume on the order of 30 km^3 (length of separation wall 14.8 km) is of the same type. The avalanche mass traveled up to 17.5 km, crossing a ridge up to 600 meters high on its way and covered an area of 165 km^2 (Harrisen, Falcon, 1937).

4. Seismovibration Landslides and Landslips

Obviously, in individual rare cases the scale of seismic dislocations depends not only on the intensity of the earthquake, the depth of the center, the type of seismogenic structure and geology of the area, but also the duration of the semismic vibrations. Thus, on the Black Sea coast of the Caucasus (Tuatse-Anap) A. B. Ostrovskiy (1970a,b) established a mass development of characteristic landslides, shifts of the mountain elements, powerful fractures, and so on, the formation of which is connected with the disastrous earthquakes of the past. When studying this area in 1971 on the Abrau Peninsula (between Novorossiysk and Anapa) we encountered the basic type of geodynamic phenomena: enormous

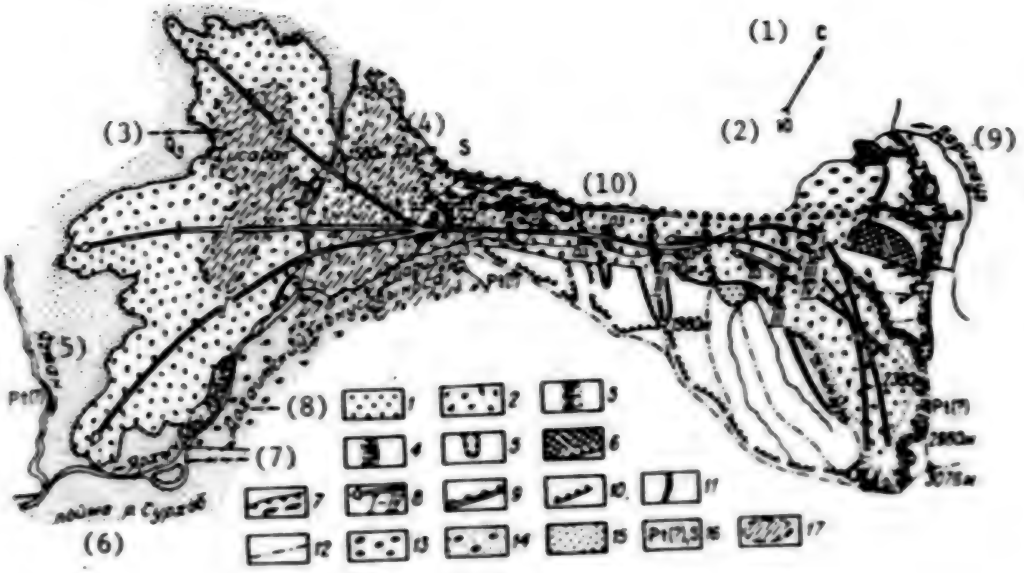

Figure 3. Plan View of the Khait Landslip on 10 July 1949 drawn by V. P. Solonenko.

1 -- swells of ancient avalanches; 2 -- Khait Landslip; 3 -- scarps of the avalanche mass waves; 4 -- rock-avalanche amphitheaters; 5 -- landslip amphitheaters in loess; 6 -- seismogenic rocky landslide-landslip and direction of its movement; 7 -- landslides and protruding knolls; 8 --direction of motion of the landslips (I-IV -- their successive phases); 9 -- seismogenic upthrow fault; 10 -- seismogravitational landslip-landslide joints; 11 -- mudslide rill; 12 -- divides; 13 -- moraine; 14 -- proluvium; 15 -- alluvium (Q_3); 16 -- Proterozoic (Pt(?)) and Silurian (S) metamorphic series and granites; 17 -- outlines of populated places buried under the avalanche;

Key:

1. north
2. south
3. Khisarak
4. Khait
5. Yagman
6. Flood plain of the Surkhov River
7. Yarkhych (Obi Kabut)
8. Dokhaitskiy debris cone
9. Darikhauz
10. Lake

with respect to width (up to 100 to 150 meters) and depth (to 90 meters), but short (no more than 4 km) splits or shifts of parts of the mountains (Fig 4) covering the valleys with coarse-lump rock flows running up to 3.5 km from their source (among them, up to 2 km into the sea), at the same time as for a gravitational shift the avalanche mass could travel no more than 50 to 100 meters from the foot of the avalanche slope (maximum height less than 400 meters).

Nevertheless, even during the most powerful earthquakes known on earth, such formations have not occurred; in addition, they have not been connected with explicit seismogenic faults and they are not accompanied by a seismo-gravitational destruction of mountains of the corresponding scale. We have come to the conclusion that here we are dealing with a new phenomenon previously unknown in geology -- with a type of seismogenic-vibrational creep and disintegration of the mountain massifs caused by prolonged seismic vibrations of moderate intensity from shallow center zones in the shelf zone of the Black Sea. This phenomenon which we have called the "Pontian phenomenon" (Solonenko, Khromovskikh, 1974) can also occur in the Mediterranean Sea where extraordinarily long-lasting earthquakes have been recorded more than once in history (the last of them was on 9-13 August 1953 with M up to 7 on the Ionian Islands).

Figure 4. Vibration-seismotectonic Joint of the Utrish Structure on the Abrau Peninsula. Photograph by V. P. Solonenko

5. Seismogravitational Landslips on an Air Cushion

A unique avalanche occurred during the Peruvian earthquake of 31 May 1970 (M=7.7): 50 million to 100 million m^3 of soil and ice broke loose from Guaskaran Mountain at an altitude of 5500 to 6400 meters. The avalanche fell 1 km vertically, and then it ran 3 km along a 22° slope and 10 km along a 5° slope. The avalanche developed a speed of no less than 280 to 385 km/hr, and according to ballistic calculations (the multiton lumps were thrown to the side up to 1600 meters), the speed reached more than 450 km/hr which made it possible for the avalanche mass to be hurled across a ridge 230 meters high, across the Rio Santa Valley and travel 83 meters up the opposite side. Mud traveled 160 km along the Rio Santa River to the sea, destroying a bridge and a hydroelectric powerplant.

In places where the avalanche passed, the vegetation and soil layer turned out to be undisturbed. The investigators of the avalanche explained this fact (just as the enormous speed of the avalanche) by the fact that the avalanche mass moved on an air cushion (Plafker, et al., 1971).

6. Slipping Landslides

In areas made up of moderately dislocated sedimentary or volcanogenic-sedimentary formations during earthquakes in statically stable sections bands of beds up to several square kilometers in area slipped. Thus, during the Dagestan earthquake on 14 May 1970 (M=6.6, I_0=force 9), numerous slipping landslides were formed. The Achiyskiy landslide (~10 million cubic meters) 1 km long crossed the Chvakhun-Bak Valley and blocked it. The graben-like trench up to 180-200 meters wide and 40 meters deep formed on the slope. Higher up on the slope another seismogenic line of joints was formed which prepared a new landslide (Klimenko, Tsarev, 1971). At another location, the sliding of one of the peaks of the cuesta created the illusion of shearing of the mountain peak.

In the case of sharply expressed bedding, schistosity or tectonic jointing planes, the slipping landslides can also occur in crystalline rock.

7. Seismogenic Earth Avalanches and Streams

On the slopes of mountains covered with talus, placers, and, especially, loess soil, a mass of landslides, mud streams and landslips develop The latter are especially dangerous. They move similarly to snow avalanches. The individual earth avalanches can cross valleys and travel hundreds of meters up the opposite slope. If there is a sufficiently powerful stream in the valley they can turn into mud streams. In the case of mass descent of avalanches (especially with countermovement), on collision the earth masses acquire powerful dynamic momentum, and they rush downward at enormous velocities, forming a high-speed earth stream.

Figure 5. Characteristic Microrelief of an Earth Stream.
Photograph by V. P. Solonenko.

In the case of the Khait earthquake, the earth avalanches and streams traveled into many of the valleys. Along the broad, gently sloping valley of the Yasman River, the earth stream, in spite of small bottom slopes (2 to 3°) traveled 20 km, destroying 20 kishlaks [Central Asian villages] and fertile lands. This caused the first investigators of the earthquake to conclude that a mud stream had passed through the valley. However, the study that we made later of the morphology of the slide rock, its internal structure to a depth of 15 to 20 meters and microrelief demonstrated that a seismically excited earth stream had passed through the valley although in places (in areas where the water from the submerged stream broke through) the earth mass could have assumed a mud consistency. The first inspectors did not note the mass development of the hummocks caused by the earth spouts, a distinguishing feature of seismically excited earth streams (Solonenko, V., 1970b). This microrelief (Fig 5) is usually taken as sedimentary hummocky-sinkhole relief or periglacial earth cone relief. Secondary spouting channels terminating at the surface in residual sinks of spurious craters can be seen in the cross section of the cones in the seismically excited earth streams (Fig 6). This is a reliable characteristic of the spouting cones of the seismogenic earth avalanches distinguishing them from earth mounds of other genesis.

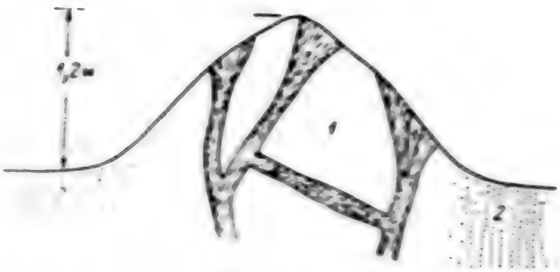

Figure 6. Earth Spout mound in the Khait Avalanche in the Ya man River Valley
1 -- pale yellow structureless loam; 2 -- the same with restored loess structure; 3 -- dark brown loam with flow texture.
The mound was formed on 10 July 1949 and it was discovered on 21 October 1968.

In seismic areas with thick loess deposits on essentially any section with a slope of more than 10 to 12° the occurrence of earth avalanches and streams is possible. Therefore the most dangerous areas must be distinguished. These should include the probable pleistoceism earthquake zones with force 8 intensity and higher. The valleys parallel to seismically active faults are the most dangerous. The formation of powerful earth streams is most prevalent in them.

Under permafrost conditions the formation of earth streams during powerful earthquakes depends to a high degree on the state of the active layer: in the winter when the active layer has merged with the permafrost, they cannot occur in general (the Tas-Yuryakhskoye earthquake on 18 January 1967, force 9-10, M=7); at another time the melting part of the active layer slips, and depending on the degree of wetting, earth avalanches or mud flows are formed (the Oymyakonskoye earthquake on 18 May 1971, force 9-10, M=7; see Kurushin, et al., 1972).

In the seismic zones with broad fields of thick friable deposits, especially loess, the earth avalanches and streams can be widely used to discover the pleistoceism regions of preseismostatistical strong earthquakes.

When there is sufficient flooding, the earth streams become the mud flows which in general frequently accompany powerful earthquakes (Solonenko, V., 1963c).

Role of the Paleoseismogeological Method in Forecasting Landslides and Landslips

In the paleoseismogeological method broad use is made of the traces of ancient seismogravitational deformations.

The paleoseismogeological data on the pleistoceism zones of the most severe earthquakes of this century accompanied by disastrous seismogravitational phenomena indicate that the largest landslides and landslips have a stable tendency to repeat in certain areas (Solonenko, V., 1972a, b; Solonenko, 1972a, b).

According to our observations, this is connected with two principal causes: 1) high stress of the rock masses in the body of the seismogenic structure and 2) with the preparation of new rock masses for avalanching during preceding earthquakes.

The stress of the rock in highly active seismogenic structures is so great that the landslips frequently occur without any apparent reason even on slopes that are stable with respect to outward signs. Thus, in the Central Graben of the Dovachanskaya Seismogenic Structure (see Fig 7) by aerovisual observations we were able to photograph the avalanching of a slope 2.5 km long (Fig 8). During field examination of the structure in 1962 two avalanches occurred before our eyes on a single day.

The characteristic sign of the landslips in the overstressed massifs is splitting of the rock, frequently independently of the existing weakened planes. The blocks (in our case up to 1.5-3X5 meters) have the shape of detritus obtained when taking samples of rock for crushing, and the fresh cleavage planes are powdered with granite dust (ACTIVE TECTONICS..., 1966, p 30).

These landslips cannot date strong earthquakes, but they are a reliable index of the high seismic potential of the seismogenic structure.

In the areas with powerful seismogenic landslips and landslides, conditions are simultaneously prepared for the following shifts: gravitational-seismotectonic and seismogravitational joints encompass new large areas (Solonenko, V., 1978, b, 1972a, b), often reaching the divide on the opposite slope. To the side of the seismically active faults on steep mountain slopes smaller landslips and landslides are prepared which is reflected in the seismogenic (seismogravitational) settling of the slopes.

When predicting landslides and landslips it is necessary to realistically consider that the estimation of the seismogenic-gravitational stability of the slopes by mathematical models (considering the regional forecasting) is impossible; therefore the forecasting of seismogravitational danger must be carried out primarily by the seismostatistics and the paleoseismogeological data (on an engineering-seismogeological base).

The engineering-seismogeological regions where there are traces of powerful seismogravitational phenomena must be closed to large-scale construction. For example, the village of Khait, which was destroyed by the landslips of 10 July 1949, was constructed in the path of two earlier such landslips, and now everything is ready for a fourth seismogenic landslip (Solonenko, V., 1970a,b, 1972a, b).

Figure 7. Central Graben of the Dovachanskaya Seismogenic Structure.
Photograph by R. A. Kurushin.

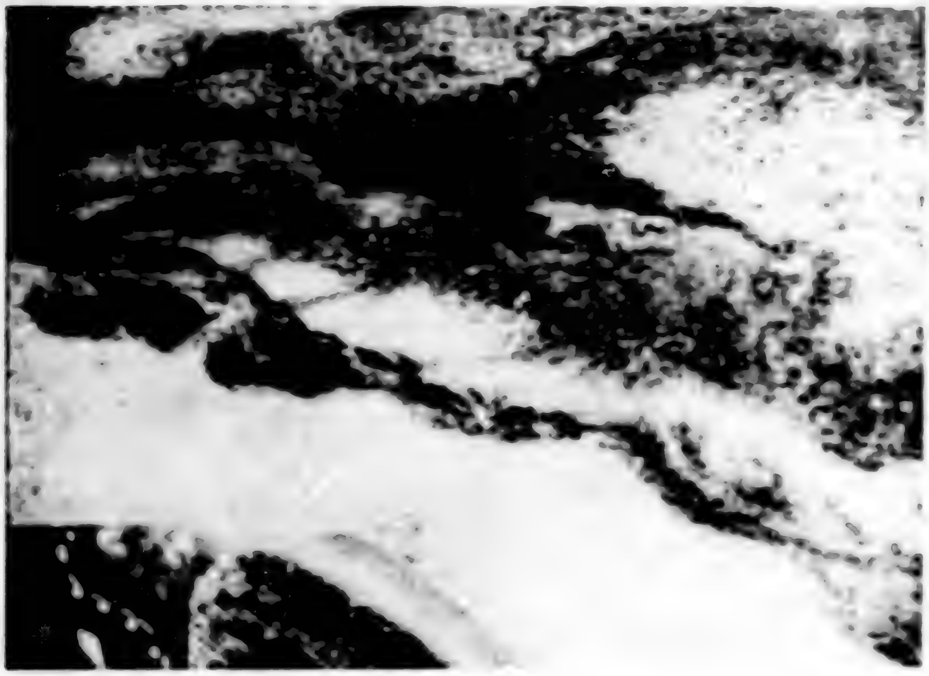

Figure 8. Avalanche in the Central Graben of the Dovachanskaya Structure (left scarp in Fig 7). Photograph by V. P. Solonenko.

in the vicinity of Sarezskoye Lake (61 km long, up to 505 meters deep) formed as a result of the seismogenic landslip on 18 February 1911 (M=7) there are traces of far more ancient landslips. At the present time on the right bank of the lake more than 2.2 km^3 of rock are ready to avalanche. On the left bank fissures have loosened a mass of rock extending 2.5 km. Thus, it is clear that the Sarezskoye Lake can at any time become a source of disaster in the Bartang, Pyandzh and the Amudar'ya Valleys. A special commission on Sarezskoye Lake working in 1967, made a conceptually correct decision but one that is erroneous with respect to specific recommendations: in order to guarantee stability of the Sarezskiy slide rock, it was proposed that the level of the lake be lowered by 100 to 150 meters, building an 800,000-kilowatt hydroelectric powerplant (Poslavskiy, 1968).

The commission began with the fact that when more than 2.2 km^3 of slide rock avalanches into the lake, its level can rise 50 to 60 meters and reach the crest of the slide rock, that is, only the possibility of a simple rise in water level was taken into account. By the existing analogy, the wave height during such a slide can reach many hundreds of meters,[1] and even if

[1] During the earthquake on 10 July 1958 in the Lituya Bay, a landslide totaling 30.5 million m^3 caused the water to splash to a height of up to 516 meters. Giant waves were noted in the same bay during the earthquakes of 1853 or 1854 -- ~120 meters, 1874 -- ~25 meters; 1899 -- 61 meters; 1936 -- 147 meters (Miller, 1963; Tocher, 1962).

it does not break through the slide rock, on falling from the kilometer height it will destroy the hydroelectric powerplant, and everything in the Bartang Valley below.

Inasmuch as the statistical data have decisive significance for predicting seismogravitational phenomena, we consider it extremely important to catalog them.

Seismogenic Sedimentary Facies

In addition to the direct signs (seismic dislocations and seismogravitational phenomena) the seismogenic sedimentary facies can indicate earlier powerful earthquakes even for periods when there have been flareups of seismic activity (ACTIVE TECTONICS..., 1966, pp 29-34). The intrusion of the coarsely clastic, unsorted sediments which were unlayered or have undeveloped bedding, into the rhythmically constructed foothills section, intermontane basins and large valleys, especially with anomalous development with respect to area and remoteness from the feed areas, can indicate the relation of such deposits to the disastrous earthquakes. On the contrary, the introduction of fine-grained sediments into the coarsely clastic alluvial and proluvial deposits of the mountain valleys and basins indicates the sudden formation of subchannel facies which can be connected with covering of the river beds with seismogenic landslips or seismotectonic dams. In the mountains of Tyan'-Shan', Pamir and the adjacent regions of Afghanistan, many lakes are known which were formed as a result of chocking of the rivers by seismogenic landslips from tens to many hundreds of meters high.

The valleys of many of the streams flowing into the Baykal were covered by the landslips, in part seismogenic. For example, the valley of the Selengushka River (the right tributary of the Snezhnaya River) at the Snezhnaya seismogenic structure was filled with slide rock to a height of about 100 meters. The dam obviously was broken twice, but now a chocked lake about 2 km long still remains.

The sharp replacement of the lithologic types of sediments can be caused by earth and mud seismogenic streams. Thus, in the case of the earthquake of 9 June 1887 in Zailiyskiy Alatau (Mushketov, 1890), there was a mass formation of earth (loess) streams. In the ore-bearing valleys, they frequently became mud flows. The deposits of these flows formed terraces up to 50 meters high. Many of them went out on the plain and covered it with a slick up to 8 to 12 km in radius in the mouth of the ravines. In all of these cases the fine-grained deposits, without any intermediate sediments with respect to granulometric composition covered the coarsely clastic alluvial-proluvial deposits.

It is natural that it is impossible to isolate the seismogenic facies of the sediments only with respect to sharp replacement of their lithology, and careful complex analysis of the paleogeographic conditions of the

accumulation of sediments, the tectonic regime of the districts and the seismogenic phenomena of all types is necessary.

The colluvium of the slide rock facies in the zones with high seismicity is significantly more widespread than was assumed earlier. Its greater part is documented as glacial deposits or water-rock streams. The composition of the landslide maps depends on the geological, tectonic, geomorphological conditions, the kinetics of the landslip, the intensity of the earthquake, the degree of intensity of the rock massifs and geographic medium.

In the case of the landslip faults, the shifted masses are split into enormous blocks. In the first stage often the soil and plants layer is retained. The surface of the advance, most shifted stages is covered with gravel-block landslide material coming down off the slopes of the upper scarps. On the surface of the landslip-fault stages, the loose material during the course of the shift (more precisely, at the time of its sharp inhibition or cessation of motion) spurts and forms deposition cones. The surface of the scarps covered with such cones, resembles in the fresh form the colonies of termite structures (Solonenko, 1963a, 1970), and subsequently, their microrelief is similar to the soffosion-subsidence relief.

On the frontal edges of the seismogenic landslides sometimes characteristic cupolas are formed from extrusion of clastic material up to 10 meters high or more (Solonenko, V., 1963, b, 1966, p 31).

The index of seismogenic nature of a landslip can be the nature of the clastic material itself and the morphology of the landslip mass: the cascade profile, the large blocks -- obelisks, and so on -- squeezed out of the general, more or less uniform mass (Solonenko, V., 1970b).

Sometimes it is possible to establish the correlation between an exotic layer of sediments and a specific seismogenic structure. Thus, for example, two large landslips chocking the Shartlay River Canyon are genetically connected with the Shartlay seismogenic structure. The traces of the water and rock mudslide formed on breakthrough of the land-slip dam can be seen in the cross section of the remains of the debris cone preserved in the mouth of the canyon. The debris cone of that time along the upthrust bank was dropped and covered with modern proluvium. The upper horizon of the proluvial deposits differs sharply from the stratified, ordinary proluvial deposits underlying it -- it is large-block with boulder-block-rubble fill. The basic material of it is characteristic of landslip facies and not for proluvial-alluvial facies like the material of the remaining horizons of the debris cone. It does not have anything in common with the material of the moraine deposits. The exotic nature of this layer indicates the exotic conditions of its formation (Solonenko, V., 1962b, 1963c).

Simultaneously, the disastrous development of the landslide facies of a significant area can be a sign of their relation to strong earthquakes. These landslide facies are known on the south shore of Baykal and in the vicinity of Lake Gusinyy in Transbaykal.

Volcanogenic formations can indicate activation of seismic activity. In the Stanovoy sector of the Baykal rift system it is possible to see four ages of seismic activation when the deep magma-conducting fractures were formed: in the upper eopleistocene, the lower pleistocene, the upper pleistocene to lower holocene and upper holocene. We are observing echoes of these events at the present time. The epicenters of many weak earthquakes, sometimes earthquake trenches (to dozens per day) with a depth of centers of about 25 km are coordinated with the pleistocene-holocene and holocene volcanoes.

The constant formation of neptunic dikes takes place in the seismically active regions. On examining the pleistoceism zones of modern powerful earthquakes (force 9-12, M=6.5-8.5) and studying the paleoseismodislocations, we observed the formation of seismogenic neptunic dikes of two types: ascending and descending. The ascending dikes are formed by the introduction of wet or water-bearing soil into the fissures, as a rule, sand, silty, sandy and other types of soil. When reaching the surface they spout and form mud cones. The neptunic dikes (or systems of them) can be of significant length. For example, in the case of the central Baykal earthquake of 29 August 1959 (force 9, M=6-3/4) the main line of the mud discharges was about 10 km long. The stripping of the soil demonstrated that there are fissures filled with silty sand -- quicksand -- running between the mud cones (Solonenko, V., Treskov, 1960).

The descending dikes are formed on filling of the seismogenic fissures with clastic material which travels upward. This type of neptunic dike is developed quite broadly in the seismic regions, especially where the seismodislocations are connected with shearing of the earth's crust. Absorption of clastic material takes place in the fissures for tens and hundreds of years. The preservation of the seismotectonic fissures in the relief is possible only as a result of this mechanism; otherwise they are quickly leveled. In such fissures, frequently sinks are observed -- absorbing swallow holes from fractions of meters to tens of meters deep and in diameter. In the fissures and swallow holes, not only is finely clastic material absorbed which is removed from the slopes, but also blocks up to enormous ones of 12 to 15 meters inclusively (ACTIVE TECTONICS,..., 1966, p 193; Khromovskikh, 1965, p 60). The thick (up to tens of meters) neptunic dikes filled with their own breccia, extraordinarily nonuniform with respect to granulometric composition are formed in this way. These dikes reach some depth still unknown, but in many cases it is no less than many tens, and more often, hundreds of meters, for the depth of the swallow holes in their body reaches 50 meters or more (Solonenko, V., Khromovskikh, 1974).

The mylonites ("tectonic clay") are a special type of seismogenic (seismotectonic) formation. As the experience of the Gobi-Altay earthquake has shown, the mylonites are formed from the most varied rock (from argillites to granites), but they basically are of one composition -- hydromica-montmorillonite. Their established thickness is up to 1 meter. They have been formed not only in practice instantaneously, but wer squeezed out of the cracks like paste and in places form walls more than 1.5 meters high (Solonenko, V., 1963a, pp 323-326; Solonenko, 1965, 1966, pp 342-345).

The deposits of the so-called turbid flows can occur as a special type of seismogenic sediment in the large bodies of water.

Previously attention was given to the fact that the sharp replacement of the deep water sediments with shallow water ones, the more so, with coastal fauna and ripple marks with stratigraphic discontinuity is considered as unconditional proof of the course of events: 1 -- rapid tectonic uplift of the sea floor, 2 -- regression of the sea, 3 -- continental deviation, 4 -- transgression, 5 -- restoration of the deep water regime. It is clear to every geologist that at least tens of millions of years are needed for this course of events. In reality, this can occur in a calculable number of hours (Solonenko, V., 1970a, p 25). This type of extraordinary stratigraphic section can be created by seismically excited earth streams -- subaqual mud flows (Solonenko, V., 1973a). As a result of precise recording of the time of earthquakes and damage to underground cables, significant factual data has been accumulated on the movement of the seismically excited subaqual mud flows. The Grand Benis earthquake of 18 November 1929 is a classical example (force 9-10, M=7). During this earthquake, 12 cables located up to 800 km from the epicenter were successively broken. The speed of the subaqual mud flow was about 90 km/hr on the continental slope, and 36 km/hr in the abyssal plain.

During the Algerian earthquake of 9 June 1954 (force 9, M=6-3/4), five underwater cables were broken laid at a distance of 6 to 100 km from the coast of Algeria. The speed of the flow on the continental slope was 60 km/hr; on the deep water plain it dropped to 8 km/hr. These speeds and the length of path of the subaqual mud flows not attainable without seismic excitation explain their gigantic erosion activity, the penetration to a depth of up to 4200 meters of the coastal coarsely clastic deposits (Gudzon Canyon) forming cones at the mouths of the underwater canyons which are morphosculpturally similar to the proluvial debris cones and absence of a connection between some of the canyons not only to the continents and mouths of rivers, but also to the shallow water (the canyons on the Marian underwater ridge 200 km south of Japan).

The underwater canyons and anomalous distribution of the sedimentary facies are characteristic not only for the seas, but also for the large continental bodies of water in the highly seismic regions. In the Baykal basin there are underwater canyons and intrusions of coarsely clastic deposits into the deep-water sections of the basin and sections free of sediment to a significant depth. All of this is unexplainable without considering the powerful seismic oscillations.

The isolation of the seismogenic facies of the sediments from lithologically similar formations requires a great deal of attention and cannot always be reliably accomplished. The most frequent error which must be encountered when using the materials of other geologists is the classification of the seismogenic landslip and proluvial-landslip facies as glacial, although, in our opinion, they are comparatively easily distinguished (with respect to shape of the clastic material and blocks, composition, nature and compo ition of the filler, the glacial striation or absence of it, the cumulative micro and mesoforms of relief, the configuration of the earth covered ·y the deposits, the accompanying morphosculptural phenomena, and so on).

It is appreciably more difficult to distinguish the solifluction rock streams from the seismogenic landslip and landslip-proluvial formations at the feet of the mountains (the oblique piedmont plains). Here it is necessary to consider that in the pleistocene and part of the holocene the permafrost was developed appreciably more broadly than at the present time, and the solifluction processes had a regional nature. In some cases, the coastal breccia of the disappearing bodies of water, the avalanche deposits of other formations of the colluvial type can cause confusion. For diagnosis of the sediments it is necessary to study the areas of their propagation, thickness, composition and relations to the seismogenic structures, and so on.

Age of Paleoseismodislocations

The determination of the more or less exact age of the paleoseismodislocations still remains a weak place in the paleoseismogeological method. This is connected not only with procedural but also practical difficulties. Until recently both in the USSR and world practice only our small collective at the Laboratory of Seismogeology of the Institute of the Earth's Crust has been engaged in systematic paleoseismogeological research. In the remaining highly seismic regions of the earth, the method, although used quite broadly in recent times, has been used sporadically, for the most part when examining the pleistoceism zones of modern powerful and disastrous earthquakes. The determination of the exact age of the paleoseismodislocations requires painstaking, detailed studies, as a rule, with a large volume of earth work.

For determination of the age of the residual seismodeformations, the following methods have been used and can be used in the future: geological, engineering-geological, historical-archaeological, dendrochronological, and radio carbon.

By the usual geological methods, in the overwhelming majority of cases the age of the residual seismodeformations can be determined highly approximately, which can have great significance for knowledge of the evolution of the seismic activity of the region, but not for applied purposes. In order to determine the level of modern seismic activity of the neotectonic structures it is necessary to know the events of no more

than the first thousands of years ago. The extrapolation of the events further in the past to modern times can lead to the grossest errors: in all seismic regions where corresponding materials were obtained (Mongolia-Baykal, Central Asia, the Caucasus, Mediterranean, Iran, and so on) the seismic activity of several thousands of years ago changed sharply, as a rule, in the direction of a decrease.

The paleoseismogeological data are a chronicle of the most powerful earthquakes imprinted in the geological-geomorphological documents of the earth's surface. By these data, in the Baykal rift zone we have established four outbreaks of seismic activity. In the region of the expansion of the rift zone on its eastern flank in the upper holocene, the seismic activity increased sharply in connection with the migration of the riftogenic processes to the east of the apparent end of the rift system (Solonenko, V., 1968a, b), and on the southwestern periphery, in eastern Sayan, it decreased.

In the northwestern Caucasus, according to the paleoseismogeological analysis A. B. Ostrovskiy (1970a)isolates two ages of activation of the seismicity: 1 -- approximately in the middle of the late pleistocene and 2 -- historic, ending at the beginning of the first thousand years A.D.

With respect to the paleoseismodislocations in the vicinity of the Talaso-Fergan fault, V. K. Kuchay (1971) establishes the maximum of the seismic activity at about 50,000 years ago, a reduction in the maximum force of the earthquakes, 10,000 years ago. The modern earthquakes are the weakest in a 50,000-year period. The paleoseismodislocations have been widely developed in the vicinity of the Dzhungar fault (Voytovich, 1969). Nevertheless, the modern seismic activity of it is low. This can either indicate recent changes in the seismic regime or temporary seismic quiet. The importance of the statement of special paleoseismogeological research in such areas is obvious.

It is possible to use the engineering-geological methods for approximate dating of specific seismodislocations. Data on the rate of destruction of the rock and movement of the soil on the slopes can be used for this purpose.

Wherever the bedrock has been uncovered as a result of seismic deformations, the time of this slipping can be calculated by the depth of destruction of the rock.

Under the conditions of the Baykal region, the formation of talus, including structural, takes place at greater speed (cm/year): diabases 1.3; granites 2.3; granite-gneiss and gneiss 3.3; crystal limestones, marble, massive Jurassic sandstones 4.0; thin-layered Jurassic sandstone 9.0 (Solonenko, V., 1960b, p 17). B. A. Agafonov (1974), who performed special observations in experimental areas on crystalline rock obtained

the same rates: 12.5-87.6 mm/year. It is natural that the weathering proceeds nonuniformly, the rates gradually change, and on reaching the thickness of winter freezing of the ground, they drop sharply although the formation of the talus does not cease (as a result of annual fluctuations in temperature and chemical weathering).

In the case of conservation of the seismogenic deformations on the steep slopes or at their base, some idea of their age can be obtained from the calculations of the speed of movement of the ground. However, in this case we can, as a rule, obtain only the upper age limit, for in the seismogenic joints usually intense absorption of clastic material takes place, and the height of the scarps can vary during the course of subsequent (after the earthquake) movements of the earth's crust.

The speed of the loose material under the conditions of Baykal seismic belt is very high: in the bald peak zone, on slopes of 30 to 35°, the soil is shifted 4 to 5 cm/year (Agafonov, 1974); the speed of movement of the placers is up to 145 cm/year, the denudation meter is in places only 210 years (Solonenko, V., 1950, 1960b). Prospecting channels frequently are completely leveled in a few years. The cuts on the Krugobaykal railroad up to 6 to 8 meters deep abandoned in 1912-1914 not only were filled with talus by 1941, but in places forests had appeared on them. These constantly active factors, to say nothing of the "volley" removal of material from the slopes (during rain, avalanches and so on), must level the static forms occurring during earthquakes of an intensity of force 9-10 during the course of 10-15 to 100-150 years. However, the joints remain for a longer time, for the clastic material is absorbed in them.

In recent times efforts have been made to determine the seismodeformations and their approximate age by cave structures (Langer, 1970).

The archaeological and historical data can give more exact information about the seismodislocation time. The breaching of encampments and settlements by a seismogenic structure offers the possibility of determining its upper age limit. For example, by the presence of the late neolithic culture, the age of Posol'skiy Sor -- the analog of the Proval Bay on Lake Baykal -- has been established at no more than 2000 to 3000 years; by the dynamics of the shoals and sandbars, no less than 500 years (Rogozin, 1974). The second figure is closer to reality, for at the end of the 17th century and beginning of the 18th century the remains of the trunks of a submerged forest still stood in the bay.

There are especially broad possibilities for using historical data in long inhabited areas with a thousand-year culture. For example, when studying the consequences of the earthquake of 31 August 1968 in Iran it was established that in the last 100 to 200 years the underground water galleries are shifted by more than 10 meters to the left (Ambraseys, et al., 1969, p 10).

V. G. Trifonov (1971) described the shift of the Kahriz-well line above the underground water galleries in the vicinity of the Main Kobet-Dag fault. Depending on the time of construction, the Kahriz lines were shifted from 8 to 3 meters. Now, from the historical and archaeological studies seismologists and seismogeologists can ferret out a great deal of important information about powerful earthquakes frequently well dated, as we have done when studying the seismogeology of the western Caucasus (Solonenko, V., Khromovskikh, 1974).

The historical and archaeological data can be direct and indirect. There is no doubt that their role in the dating of the powerful earthquakes of the past, the time of formation of the seismogenic structures, determination of the recurrence rate of the catastrophic earthquakes, and evolution of seismic processes will increase quickly.

The dendrochronological method is applicable for dating seismogenic structures in the forest zone. It most easily offers the possibility of determining the lower age limit of the structure with respect to the age of the trees growing in the seismodeformations ("a structure no younger than N years old").

Exact dating is possible for young structures in which the trunks of the felled trees or, by fortunate accident, uprooted trees were preserved. The correlation of the annual rings of live and dead trees can permit determination of the year of formation of the seismodislocation.

The dendrochronological method has been used in the pleistoceism zone of the Mississippi earthquake of 1811 for separation of the Mississippian and pre-Mississippian dislocations and in Alaska (Page, 1970).

The experience of the application of dendrochronology in the Baykal region has demonstrated that already at 10 meters from the seismodislocation the trees do not experience significant disturbances in the nature of the wood, which must be strictly taken into account when using this method.

The radio carbon method appears to be the most prospective. For certainty of the correctness of the analysis, it is necessary to extract from the seismodislocation organic remains which could not be brought in after the earthquake, which is impossible to do without serious mining operations, but we still have not had this possibility. Nevertheless, its application offers the possibility not only of dating the time of seismic disasters, but also determination of the direction of the slow movements of the earth's crust during the period between seismic disasters (Plafker, 1968).

In spite of the tempting nature of dating the seismodislocations by the radio carbon method, it is impossible not to give attention to the fact that the seismically active faults are special geochemical zones, and the primary C^{12}/C^{14} isotope ratio in the plants in the seismogenic zone can be different than usual, which can lead to sharp distortion (increase) in age).

Force Scale

> Wherever you see rock with cracks, the traces of an earthquake are unquestioned; the more severe, the more unstable the debris, the race and the mud.
>
> M. Lomonosov (6 September 1757)

The empirical data obtained when investigating powerful earthquakes indicates that the size, the types and morphology of the residual deformations for the seismogeologically uniform zones are more or less constant. This offers the possibility of solving the inverse problem: with respect to the seismogenic residual deformations to determine, of course, approximately the intensity and magnitude of the preseismostatistical earthquakes.

This scale cannot be universal for all seismic zones. The scale and type of the seismodislocations and the gravitational phenomena depend not only on the energy of the earthquake but also on many other factors: the depth and mechanism of the center, the type of seismogenic structure, the orientation of the center zone, the geological structure of the relief, and so on. For example, the area encompassed by the seismogravitational phenomena, their type and sizes depend on the regional engineering-geological (including the geocryological) conditions. Therefore it is impossible mechanically to transfer the force scale from one seismic zone to another. It is also impossible to create a universal formula for calculating the theoretical isoseismal lines, although seismologists propose and use them for theoretical and applied purposes. One thing is certain: each powerful ($M \geq 6.5$) earthquake with a crustal center leaves its traces on the surface of the earth, but until recently only a few simply knew how to see them.

The scale of the residual deformations usually is appreciably greater than indicated in the scales of the seismic intensity, including in the most perfected of them -- the MSK-1964 (Medvedev, et al, 1965).

The first scale with respect to residual deformations was proposed about 15 years ago (Solonenko, V., 1962b). Recently broad new factual material has been accumulated which was collected when studying both modern earthquakes and paleoseismodislocations in various highly seismic zones of the earth. On the whole, it confirmed our scale of 1962, and has not required the introduction of theoretical changes into it.

Force 8 (M=5-1/2 to 6-1/2). The regional and zonal seismotectonic phenomena can be established only by geodetic studies, but they also still do not always provide undisputed material. The changes in the relief and hydrography from the paleoseismogeological points of view are difficult to detect and still more difficult to prove. The local dislocations, as a rule, do not reach the surface of the earth or they are insignificant with respect to size; therefore they are quickly destroyed by denudation.

Nevertheless, under favorable conditions, especially in the dry steppe region, on the basis of the aerial photographs the local seismodislocations sometimes are manifested on the surface of the earth and can be detected, for their extent sometimes is quite significant. For example, for the earthquake of 14 December 1950 in California (M=5.6) three faults were formed with a vertical displacement amplitude to 0.2 meters on a path with a total extent of about 9 km (Richter, 1963, p 477). In the central Sudan in the case of the force 8 earthquake (M=5.7), a strike-slip fault about 4 km long was formed in 1967.

In the Baykal seismic zone alone in one case opening of a fault was observed for an earthquake of modern intensity (to force 8?) 2 November 1958 (M=4-3/4, but, possibly, low).

The epicenter of the earthquake was located in the vicinity of the Khaniyskiy fault at the point of intersection of the Olekma River by it. Along the fault cutting the silicified precambrian crystalline limestone of the Udokan series of the late proterozoic, joints were formed running 200 to 250 meters. As a result of the opening of the old fault, absorption of the block material of the placer covering the rent began (Kochetkov, 1964, p 41).

They differed from the seismodislocations connected with the force 9 earthquake by the small amplitudes of the shifts (the difference in maximum shifts was 10 to 15 times).

In order to discover the epicentral zones of the force-8 earthquakes, the seismogravitational phenomena appeared to be more reliable. The basic difficulty here is to establish the simultaneousness of the formation and independence of them with respect to exogenic causes. In the force 8 isoseismal field of earthquakes with an intensity of force 9 or more, the residual seismogravitational deformations develop over a larger area than for the force 8 earthquakes. Pseudotectonic deformation can occur here. For example, in the case of the central Baykal earthquake of 29 August 1959 (M=6-3/4, force 9, h=18 km) in the force 8 zone, a line of mud eruptions about 10 km long was formed (at an epicentral distance of up to 43-45 km). The cones of the mud volcanoes are associated with the cracks which are oriented along the lines of the large blind faults covered by a series of neogenic-Quaternary sediments 370 to 700 meters thick. The established width of the cracks is to 10 cm. They were filled with sand and quicksand injected from below (Solonenko, V., Treskov, 1960).

Such neptunian dikes can be used for determination of the pleistoseism regions of the preseismostatistical earthquakes. They differ from the ordinary neptunic dikes by the presence of repeated spouting channels. Otherwise they are difficult to distinguish from the exogenic neptunic dikes.

In the sharply broken mountain regions in the force 8 (and higher) isoseismal area mass landslips occur. Under other equal conditions their

number, size and paths of motion after a force-8 isoseism are sharply reduced, which for regional engineering-seismogeological studies will permit more or less certain outlining of the force-8 zone.

Force 9 (M=6-1/2 to 7)

The regional and zonal deformations during force 9 earthquakes are clearly exhibited only under especially favorable conditions, predominantly on the low-lying banks of large bodies of water. The geodetic studies indicate movement of the earth's crust with amplitudes exceeding the possible observation errors in an area to 600-800 km^2.

The local seismodislocations are represented predominantly by seismotectonic fractures and only in two cases have we been able to observe gravitational-seismotectonic subsidence which can be connected with the force 9 earthquakes.[1]

On the path of the seismogenic fault or in the cracks connected with it, joints are formed which extend tens or hundreds of meters and, rarely more than 1 km. The total extent of the joint zone reaches 2 to 3 km, and in the case of predominance of the shear component, sometimes up to 10-12 km. In the latter case obviously we are dealing not with the consequence of an earthquake, but with total residual deformations connected with the main shock, its aftershocks and the shifts taking place after the earthquake. The initial maximal amplitude of the vertical displacement can increase from 0.8-1.2 to 3-5 meters.

The significant seismogravitational deformations are observed over an area of up to 600-800 km^2, randomly to 5,000 to 6,000 km^2. In the force 9 isoseismal area of force 10 earthquakes under the corresponding conditions, seismically excited earth and rock streams occur.

Force 10 (M=7-7-3/4)

In the case of force 10 and more powerful earthquakes, depending on the type of seismogenic structure, the morphostructure and geological structure of the seismic region, the regional and zonal residual deformations of the earth's crust are manifested to a different degree, and various types of seismodislocations are formed with different extent, amplitude of the vertical and horizontal shifts, gaping of cracks and the nature of the seismogravitational and other accompanying phenomena. In the case of the upthrust faults, powerful, but short (from several kilometers to 15 km, in the case of strike-slip normal faults up to 30 km) joints

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[1] STRUKTURY LABSKALDI I TSERI NA KAVKAZE [Labskaldi and Tseri Structures in the Caucasus] (Solonenko, V., Khromovskikh, 1974).

occur up to 15-20 meters wide (for upthrust faults, strike-slip thrust faults and overthrusts the fractures are predominantly closed) with an amplitude of vertical displacement of up to 7 to 8 meters. For shifts, the joints are less expressed, but the total extent of the zone can reach 100 km. The zonal deformations are the most obvious in the case of block seismogenic structures. The blocks 250 to 300 km^2 in area are shifted. Sometimes graben-like subsidences and stripping of the mountain peaks occur.

The seismogravitational phenomena occur over an area of up to 40,000 km^2. The landslips reach gigantic dimensions and often generate seismically excited rock streams. Under favorable geological-geomorphological conditions, especially in the loess areas, mass development of earth avalanches is observed which can form seismically excited earth streams often more destructive than the earthquake itself. In the case of sufficiently detailed studies the morphostructure and internal structure of such streams permit reliable distinction of them from the formations of other genesis (Solonenko, V., 1970b, 1973a).

Force 11 (M=7-3/4 to 8-1/4)

The regional seismotectonic movements of the earth's crust encompass an area of up to 100,000 to 120,000 km^2, possibly, even more.

The area of zonal deformations depends on the type of seismogenic structures, but, obviously, it is no less than 60-90X20-30 km.

In order to discover the regional and zonal paleoseismotectonic movements of the earth's crust, detailed and exact geomorphological studies are required over a broad area which will permit establishment of a sudden simultaneous change in conditions of denudation and accumulation.

Such studies have still not been performed although the first steps in this direction have been taken in Japan (Sigimura, 1968), Alaska (Plafker, 1968) and the Caucasus (Solonenko, V., Khromovskikh, 1974).

The local seismodislocations in the case of force 11 earthquakes are formed over a significant area (thousands or up to 20,000 square meters). Two extreme groups have been isolated which have different mutual conversions (Solonenko, V., 1962b, 1973c; ACTIVE TECTONICS,...., 1966).

1. In the strain zones in the case of fault movements, powerful, but not extensive (20 km or more) joints are formed with observed amplitude of vertical displacement to 10 to 12 meters (Assamskoye earthquake on 12 June 1897, force 11, M=8.0), and with respect to the paleoseismodislocations, up to several tens of meters.

2. In the case of shifts extended (up to 350 km) fracture zones are formed with small amplitude of vertical displacement. The main fractures are made up of feathering tension and compression joints, in places

(especially in the sections where the shift changes strike) they become seismotectonic trenches up to 8-10 meters or more wide. According to the paleoseismogeological data, in the presence of force-11 earthquakes, the "broken plate" structures can be formed with radially diverging and branching network of normal faults and fault trenches up to 20 meters wide in the rocky ground (Khromovskikh, 1965).

The gravitational-seismotectonic and seismogravitational deformations can be represented by all known types. The latter encompass an area of up to 150,000 km^2 or more (at an epicentral distance of up to 350 km). The former are coordinated with the seismogenic faults and have an amplitude of vertical displacement to several tens, possibly, a hundred meters.

Force 12 ($M \geq 8$-1/4)

The sharp changes in relief and hydrography over the entire area of zonal movements of the earth's crust (established area to 7,000 to 10,000 km^2) and noticeable regional variations, over an area to 300,000 km^2 and more. The fracture zones, reactivated and newly formed, extend up to 450 km, possibly, even more (in the Chilean earthquakes 21-22 May 1960, according to the seismologic data, the fracture zone at the bottom of the Pacific Ocean was 960 to 1280 km long; see Plafker, Savage, 1970), and the established total length of the fractures in the pleistoseism region of continental earthquakes reaches 850 km (Solonenko, V., 1963a; Florensov, Solonenko, 1965, 1966).

The specific deformations of the force 12 earthquakes are gravitational-seismotectonic wedges with an amplitude of vertical displacement of hundreds of meters and shearing of the large mountain peaks. Inasmuch as the seismic accelerations during such earthquakes can be twice the gravitational acceleration, it is necessary to assume the possibility of the formation of the most improbable deformations.

Until recently, only one pleistoseism zone of a force 12 earthquake completely located on dry land had been investigated in detail with the application of a special aerial photographic survey, the informativeness of which was almost exhaustive. All of the known types of disjunctive dislocations and previously unknown deformations -- gravitational-tectonic wedge with a vertical displacement amplitude up to 328 meters and shearing of the mountain peaks -- have been established in it. The instantaneous formation of thick mylonites obviously is also a specific feature of the force 12 earthquakes (Solonenko, V., 1960a,c, 1963a; Florensov, Solonenko, 1965, 1966).

Seismic Conditions and Paleoseismodislocations

None of the existing seismologic and seismogeological methods offers the possibility of reliably determining two in practice most important elements of the seismic regime: the maximum intensity and recurrence rate of powerful earthquakes.

It is impossible in this respect to underestimate the significance of the recurrence rate charts, the seismic activity charts, the K-peak and the seismic vulnerability, that is, the seismologic method of determining the most important parameters of the seismic regimen developed by Yu. V. Riznichenko, et al (Riznichenko, 1958, 1962, 1966). However, we should also not overestimate them, for the determination of the maximum intensity and recurrence rate of the most powerful earthquakes remains their "Achilles heel": according to these data it is impossible to determine on what level the curve should be discontinued or inflected and in each seismic zone it is necessary to propose the possibility of a force-9 earthquake. The recurrence rate of the earthquakes which is close to true can be obtained only for broad (a minimum of tens of thousands of square kilometers) areas, and the area of destructive tremors (of force 8 or more) in the case of force 9 and force 10 earthquakes usually is a total of 6,500 to 8,000 km^2. This greatly lowers the applied significance of the indicated methods during seismic detailing and microregionalization.

Yu. V. Riznichenko emphasizes that the dependence of K_{max} on the activity is of a general nature and is almost identical for all of the seismic regions -- weakly and highly active. Therefore the most difficult problem is dissemination of the possible intensity of the earthquakes which requires gathering of historic material over the longest possible time (Risnitschenko, 1973). We have already demonstrated (Solonenko, V., Khromovskikh, 1974), that even for such a seismic region that is rich in seismostatistical data as the Caucasus, the Riznichenko method can give distortions of the true picture as a result of incompleteness or nonequivalent seismostatistical data. In particular, on the K_{max} map of the Caucasus (Riznichenko, Dzhibladze, 1972) the K-16 isolines cut the seismic zone of the main Caucasus fault (insufficient information!) which is unique with respect to paleoseismogeological data, and the seismic danger of the Tbilisi region (K-17, that is, more than force 10) is high (the relative redundancy of the information!). There is no doubt that using paleoseismogeological data would make it possible significantly to refine the K_{max} map of the Caucasus.

The prediction of powerful earthquakes by seismic cycles proposed by S. A. Fedotov (1968) at first glance appears enticing. At the present time this has served as the reason for broad popularization of the method. For large seismic zones it can be and is applicable, but within the limits only of theoretical-reference goals. In order to predict seismic danger for a specific local section, it is more than risky to use this method. "The main assumption of this procedure is the hypothesis of constancy of the seismic regimen. Without this hypothesis, it is impossible to determine the recurrence rate of the earthquakes" (Fedotov, 1968, p 137). Nevertheless, it is well known that we cannot talk about constancy of the seismic regimen for the local areas (the earthquake prediction used in practice is expedient only in the case where we can).

S. A. Fedotov considers that for the Japanese-Kamchatka section of the Pacific Ocean zone the average duration of the seismic cycle (the time between two earthquakes of maximum force, $M \geq 7$-3/4) is 140 ± 60 years. The average duration of the foreshock and aftershock periods is 15 years each. It is proposed that after a powerful earthquake and powerful aftershock a "normal" seismic regimen arises, of course, without disastrous earthquakes in the center zones (their dimensions are up to 100X500 km; see Fedotov, 1968, Fig 1, but the fact that this is not the case is obvious from the data on the zone investigated by S. A. Fedotov. Near Lake Hakkaido in 1894 there was an earthquake with $M>8$ and consequently, in the "center zone" a subsequent earthquake with $M \geq 7$-3/4 could be expected (with an average duration of the seismic cycle of 143 years; see Fedotov, 1968, p 124) only at the beginning of the 21st century. Actually, on 4 March 1952 the disastrous earthquake occurred with M=8.6, and in 1971, with M=7.2. The latter earthquake cannot be considered as an aftershock of the 1952 earthquake (late!), nor as a foreshock of the next maximum earthquake (early!). From the practical point of view it is entirely indifferent what this "seismic cycle" element is: the epicenter was located nearer to the island than the epicenters of 1894 and 1952 and, consequently, although "nonmaximal," the earthquake could turn out to be more harmful than the "maximal" earthquake with the epicenter located farther from shore.

On the Kii Peninsula in 1954 there were two "most powerful earthquakes" in a 24-hour period (Richter, 1963, p 546). On 7 December 1944 and 20 December 1946, two maximum earthquakes occurred in the same "center zone" (M=8.3 and 8.4) with close epicenters.

Earthquakes (M=8.3 and 8.6) with merging center zones occurred near Honshu Island on 23 October 1894 and 31 August 1896. It is possible to present a number of other examples both with respect to the Pacific Ocean and other less active zones, where the duration of the seismic cycle "is many hundreds of thousands of years" (Fedotov, 1968, p 126). The latter immediately excludes the possibility of the application of this method for the majority of seismic territories (80 to 90% of the seismically active area of Siberia).

How confusing this method can be in its practical application of earthquake forecasting can also be seen in the example of our Baykal seismic zone. For its greater part it is necessary to consider the earthquakes with $M \geq 6.5$ (force 9 and more) "maximal." During a decade there should be on the average three such earthquakes over an area of 221,000 km^2. In reality, in 1957-1967 there were five earthquakes with M=6.5-7.9; of them, three (Nyukzha, M=6.5; Olekma, M=6.5; and Tas-Yuryakhskoye, M=7) were in an area of less than 500 km^2.

In the vicinity of the Selenga River delta over an area of about 1,000 km^2 three "maximal" earthquakes occurred in a century; 12 January 1862, force 10 (M=7-3/4), 26 November 1903 force 8-9 (M=6-1/2), 29 August 1959, force 9 (M=6-3/4), and their zones of destructive tremors (force 8 and higher) overlapped each other.

All of the existing methods of analysis and forecasting of the seismic conditions are seismostatistical, but the paleoseismogeological method has the possibility of obtaining data about the strongest earthquakes in a more prolonged time period. Therefore the determination of the maximal earthquakes must be complex with respect to seismological and paleoseismogeological data. The map of the maximal earthquakes and their average (long range) recurrence rate must be matched with the seismogeological data, without which no map and no forecast can be recognized as satisfactory inasmuch as the seismic process is a geological process, which is forgotten or not considered in general by the majority of seismologists.

Research Procedure

First of all it is necessary to consider that the paleoseismogeological observations are a component part of the complex seismological, seismogeological and geophysical studies. In the case of regional and detailed seismic regionalization, and in the especially highly seismic zones -- even during microregionalization (for more precise determination of the initial calculated force) -- it is necessary to encompass areas of tens and hundreds of thousands and even more than a million square kilometers with the paleoseismogeological observations. It is natural that without preliminary serious and comprehensive preparations for field studies in such areas it is possible to search unsuccessfully for more than 1 year for paleoseismodislocations. Therefore, during the paleoseismogeological studies, they have themselves been divided into the following stages.

1. Preliminary Laboratory Preparation

According to the seismostatistical, historical-archaeological, seismological, geological and geophysical, geomorphological and other materials (depending on local conditions) the areas of probable manifestation of powerful earthquakes have been isolated, and in them, in accordance with the proposed or known type of seismogenerating structures, the geomorphological and engineering-geological conditions, the sections of more probable appearance of residual seismogenic deformations.

2. Decoding of Aerial Photographs

For the isolated regions decoding of the aerial photographs takes place. The optimal scale of the photographs is 1:30000. On the 1:60000 scale photographs, as our many years of experience have demonstrated, frequently the small seismodislocations do not find expression or they are difficult or impossible to distinguish from the photoeffects of other morphosculptures, especially in forested areas. The large-scale photographs are decoded for the sections of previously isolated structures and in the case of their aerovisual examination and field documentation.

In order to obtain preliminary quantitative parameters of the seismodislocations it is necessary to perform instrument processing of the photographs. It is easy for the nonspecialist to master quantitative decoding on an interpretoscope.

It is important that the participants in the seismogeological studies know how to obtain stereo effects without a stereoscope, which greatly accelerates the examination of the photographs (and for one field season it is necessary to examine thousands or tens of thousands of them), it makes it possible to make full use of the photographs directly in the field and sometimes to consider the details of the seismogenic and nonseismogenic morphosculptures which cannot be caught with an ordinary stereoscope (the photographs are bent for this purpose).

The results of the decoding are plotted on topographic maps on which aerovisual routes will be drawn.

3. Aerovisual Observations

Aerovisual observations must be performed not only in the sections of proposed paleoseismodislocations isolated by the aerial photographs, but also in the sections of possible active seismogenic structures isolated in accordance with the geological-geophysical data: in connection with the conditions of the discussion during the aerial photograph assembly sometimes even highly distinctive seismodislocations are not recorded on the photographs or are very unclearly expressed. Previously in remote areas we performed the aerovisual observations on the AN-2 or YaK-12 aircraft, and in nearby areas, especially during ground field operations, on the MI-1 or the MI-4 helicopters. Now the MI-2 turboprop helicopter is the most convenient for these purposes (when flying over seismodislocations at admissibly low speeds). With some skill two observers (on the helicopters MI-1, MI-2 or from the copilot's seat on an aircraft and the MI-4 helicopter, even one observer) usually are able to see the details of the morphosculptures indicating their seismogenic or nonseismogenic nature, to plot the seismodislocation plan and the plan of the accompanying phenomena on the map, determine the type of structure, approximately, and its parameters (crack width, amplitude of vertical and horizontal displacements, and so on), to take photographs and make recordings, to note the traces of the ground approach to the structure and together with the pilot, select the nearest landing site suitable for landing the helicopter.

4. Field Examination and Documentation

During the field examination it is necessary first of all to be convinced of the seismogenic nature of the morphosculpture isolated on the basis of the aerial photographs and aerovisual observations. At first glance this simple problem often requires sharp observation on the part of the geologist and free orientation in the problems of tectonics, geomorphology, engineering geology, field lithology, petrography, and so on.

The broken and plicative structures, gravitational deformations and facies of the sediments can be a consequence not of the seismogenic but other processes (Solonenko, V., 1962b; 1966, p 33).

The following can resemble seismodeformations:

1) Pseudotectonic joints frequently developed along the ancient faults and tectonic joints volcano-tectonic domes and depressions, exotectonic (diapiric and similar structures, exofolding in the river valleys), anhydrido-gypsum tectonics, joints of mud volcanoes, and in rare cases, astral structures of meteoritic craters, the joints in the folding of the heads of the beds, exogenic landslips, subsidence trenches and sediments of the slopes, landslips, landslides, including rock, connected with them. In the Caucasus we encountered curious exogenic forms recorded not only by aerial photographs during aerovisual observations, but also on the first ground expeditions as seismogenic faults -- these are the upper edges of canyons filled with the landslip mass (the vicinity of Amtkel Lake) or ancient alluvium (the kolkhid foothills on the Korodi River and east of it). The edge of the canyon itself excellently simulates a fault scarp, and the subsidence joints, the accompanying seismotectonic joints. Moreover, in the walls of such joints, the slip surfaces were formed in places with striation of the strike-slip fault type. Only a detailed investigation (in the latter case) has made it possible to establish that the general direction of the "structure" was determined by the edge of the ancient canyon longitudinal to the ridge, and the displacement in the course of the subsidence of part of the blocks in the direction of the modern canyons transverse to the ancient ones, created an illusion of shift. Inasmuch as the subsidence joints go deeper than the modern surface of the ancient alluvium, in places displacement took place under compression conditions, and grooving and slip striations occurred on the walls of the joints in the limestone;

2) Glacial and nival formations: lateral, radial and especially marginal channels, pressure moraines accompanied by glacial dislocations (especially overthrusts and large glacial erratic masses), grooves on the shoulders of the trough valleys, subglacial hollows, multistory valleys, longitudinal ramparts of lateral moraines on the slopes of the valleys, fluvioglacial forms of relief, nival troughs and swells, and so on.

The periglacial fields of the earth cones, sometimes the cones of the soffosion-subsidence relief can be similar to the seismically excited earth avalanches and streams with respect to morphosculpture. The seismogenic formations differ from the latter, as was noted above, by the presence of spouting channels which are established on excavating the cones;

3) The erosion forms, including the mud flow canyons, the runoff troughs, especially in the field with large tectonic jointing when hollow massive-pseudotectonic forms of relief are created;

4) Exogenic-gravitational forms (landslides, landslips, landslide and landslip trenches which sometimes create the illusion of seismogenic shearing of the mountain tops near the corries and horn peaks);

5) Forms of selected denudation -- prepared contacts, including tectonic, veined bodies, in the arid and semiarid landscape zones, deflation forms which are the sharpest on coincidence of the strike of a weak layer or a detritus, zone with prevailing direction of the wind;

6) Under permafrost conditions -- melting of the veined ice, solifluction swells and mountain terraces, the frontal swells of the rock streams, and spring soffosion rills;

7) Artificial shapes -- ancient irrigation systems and other hydro-engineering structures, ritual and other paths, ancient defensive structures which can extend tens and hundreds of kilometers (the Genghis Khan rampart in Southeastern Transbaykal and Northern Mongolia), sometimes making good use of the tectonic scarps in the relief, underground workings, and so on.

With the expansion of the seismogeological studies in the various geological-geomorphological and landscape zones, the list of pseudoseismogenic forms, of course, will be expanded, but the qualified seismogeologists will distinguish the seismogenic formations from similar formations of other genesis without error if not by aerial photographs and aerovisual observations, then by ground observations, although (in rare cases) it is impossible to do this with certainty without mining operations.

This is why in the initial stages of the development of the procedure we warned against excess involvement of paleoseismogeology (Solonenko, V., 1962b). Unfortunately, at the present time reports and articles have appeared on the problems of paleoseismogeology based on the published data, sometimes reinforced by deciphering the aerial photographs. This, of course, is an easy, quick way to accumulate information, but it is the shortest way to the grossest errors.

The seismogenic structures are carefully documented: a general seismogeological plan and the most detailed seismogenic deformations with its morphometry are compiled. The relation of the seismogenic formations to the tectonic structures and geological formations of the area has been discovered. The age and force of the earthquakes and also the potential seismic activity of a large morphostructure or part of it within the limits of which they have developed, and the most probable sections of residual deformations and probable paths of movement of the seismogenic landslips, earth avalanches and streams, and so on, have been established by complex signs.

In the case of detailed regionalization and microregionalization in the vicinity of paleoseismodislocations, temporary seismic stations have been set up to determine the degree of modern seismic activity of the

structure, depth and mechanism of the centers and the solution of other seismogeological problems.

When organizing seismological observations, as our experience has demonstrated, it is necessary to consider that the younger and more powerful the seismic dislocations, the lower their modern seismic activity. For example, in the powerful China-Vakatskaya structure obviously formed on 1 February 1725, only one epicenter was recorded in 1962-1964. The powerful zone of young seismic dislocations on the western shore of Baykal is slightly active. Therefore, in such seismic dislocations it is necessary to plan more prolonged seismic observations than in the dislocations with an age of many hundreds or a few thousand years.

During the period since the time of first utilization of the residual seismogenic deformations to discover the seismogenic tectonic structures and epicentral zones of powerful earthquakes, the correctness of the paleoseismogeological method has been confirmed both by subsequent seismic events and the results of our application of it and its application in almost all highly seismic zones of the world. Thus, in the northeastern part of the Baykal seismic belt noted at the end of 1956 (Florensov, et al., 1960), earthquakes occurred: Muya 27 June 1957, force 10-11 (M=7.9); Nyukzha 5 January 1958, force 9 (M=6.5); Olekma 14 September 1958, force 9 (M=6.5); Central Baykal 29 August 1959, force 9 (M=6-3/4); Tas-Yuryakhskoye 18 January 1967, force 9-10 (M=7), for force 8 (M=5-3/4-6) and more than 30 of force 6 to 7.

The paleoseismogeological studies in the Central Asian and Caucasian seismic provinces demonstrated that such earthquakes as Fayzabad, Ashkhabad, Khait, Chkhalta and others which turned out to be unexpected, anomalous for seismic regions distinguished with respect to seismostatistical, instrument and geological data, occurred in areas where there are paleoseismogeological traces of the same type or even more powerful earthquakes (Solonenko, V., 1970b, 1972a, b, 1973a-c; Trifonov, 1971; Solonenko, Khromovskikh, 1974; Nikonov, 1974). On the other hand, it has been established that at times the seismic danger or probable recurrence rate of seismic disasters is unreasonably high (Solenko, V., 1978).

The paleoseismogeological method is still the most reliable method of determining maximum earthquakes (with $M \geq 6.5$) with crustal centers and their average recurrence rate and the only method for determining the potential seismic danger of seismologically uninvestigated territories and when reconstructing the geological history of the development of the seismic processes.

Paleoseismogeology has at the present time such a strong base that it is impossible to shake its foundation, and only people who are unfamiliar with the results of the investigations of the pleistoseism regions of powerful earthquakes of the highly seismic belts of Europe, Asia, Africa, New Zealand, North and South America, can doubt its effectiveness.

The paleoseismogeological method has been sufficiently well checked out that it can be included in the mandatory set of criteria for substantiating the seismic regional, detailed and microregionalization maps.

Discussion

We have already noted (Solonenko, V., 1973c) that the paleoseismogeological method has not been subjected to substantiated criticism. Moreover, some of the specialists in adjacent sciences with seismogeology have easily come to detect paleoseismodislocations where they cannot occur or take formations of other genesis for them or to use the method to discover earthquake epicenters in ancient (before the archean) series, and so on. Therefore, at the beginning of the development of the method it was emphasized that excessive use of the proposed method can do it greater harm than unqualified criticism (Solonenko, V., 1962b).

We have constantly emphasized that the paleoseismogeological method is a component part of the complex geological-geophysical method of determining the level of seismic activity of seismogenerating morphostructures. The statement that "in the works of certain Siberian scientists the paleoseismodislocations have been taken as a barely unique ... geological criterion of seismicity" (Petrushevskiy, 1967, p 65) is based on misunderstanding. In our publications on the seismicity of large regions the main body (4/5) of works deal with the geological, geophysical and seismologic criteria of seismicity.

The quite ordinary objections of our opponents include: 1) residual deformations can occur during slow movements of the earth's crust; 2) residual deformations are not tectonic, but gravitational formations; 3) it is impossible to determine the intensity of the earthquakes by the size of the seismodislocations.

1. The occurrence of deformations of the earth's crust without perceptible earthquakes morphologically similar to seismic dislocations is actually possible (see p 51). However, the paleoseismogenic structures have been discovered, as a rule, not by one sign, but by a set of signs. The combination of seismotectonic and (or) gravitational-seismotectonic deformations with seismogravitational is the most reliable. The slowly developing deformations are not accompanied by gravitational ones which could be taken as seismogravitational.

The seismogenic deformations, as a rule, are under geomorphological conditions such that preservation of slowly developing joints is impossible (see p 43).

2. Some opponents, who have not seen seismic dislocations in reality doubt their seismotectonic nature and try to show (not by fact, but by subjective notions) that they have a gravitational or seismogravitational nature.

Figure 9. Seismogenic Structure of Abakura in Svaneti a. Strike-slip Normal Fault in Crystalline Rock. Photograph by V. P. Solonenko

Such ideas are the legacy of the old views that the residual deformations pertain only to the loose cover soil. The Gobi-Altay earthquake finally refuted such ideas, but efforts are made to revive them in one form or another from time to time. It is symptomatic that among the proponents of the surface nature of seismodislocations we do not know a single author who has examined even one disastrous earthquake. The irrefutable facts confirming the tectonic nature of seismodislocations are available in as large a number as one might like, and almost every new earthquake with $M>6.5$ and a crustal center increases the number of such facts. The comparison of the mechanism of the movement of the earth's crust connected with earthquakes determined independently by seismogeological and seismologic methods (Balakin, et al., 1972), of course, if the seismodislocations were completely and qualifiedly mapped, is in itself irrefutable proof of the deep nature of seismodiscloations.

We encountered, perhaps, the most active desire to refute the tectonic nature of the dislocations after their discovery in the greater Caucasus. The discussion in this area only inhibits the development of paleoseismogeological research in the Caucasus without substantiation. Therefore we shall present two examples.

On the left side of the Tsintskali River Canyon (15 km east of the Inguri Hydroelectric Powerplant), the Kvira structure has been mapped (Fig 9). This is a fault extending about 2 km with vertical displacement amplitude in the Jurassic sandstone-tufogenic soil. A one-sided graben has been formed on its southern section (60X500 meters). The fault cut through 5 channels of temporary streams previously flowing into the Tsintskali River, and it sent their flow together with the waters of a group of powerful springs associated with the seismodislocations through the broken divide into the Dzholori River. Two large landslips are connected with the structure. Inasmuch as the structure cuts the divide along the diagonal, it is not appropriate to talk about its landslide origin.

On the divide of the Inguri and Khumpreri Rivers in Svanetia, the seismogenic strike-slip normal fault (the Abakura structure) rejuvenated the previous deep fracture (hyperbasites with sulfide mineralization are tied to it in the structure zones). The strike-slip normal fault (amplitudes 0.5-20 and 50 meters respectively) 3.7 km long intersects the divide diagonally (Fig 10). The fracture is continuing to absorb clastic material. The depth of the closed absorbing swallow holes reaches 50 meters. A line of powerful landslips is coordinated with the zone (on its continuation to the east and west).

Just as in the first case, the gravitational nature of the Abakura structure has been excluded.

3. The intensity of the earthquakes with respect to seismodislocations is determined, as a rule, quite reliably (some examples are presented in Table 1) by conversion in terms of magnitude (according to formula (2), p 12).

Table 1

Determination of M by Deformations (M_D) and Instrument Data (M_I)

Date of earthquake	Principal zone of faults, length, km	Type of deformation	M_D	M_I	Bibliographic reference
9 July 1905	Tsetserleg, 130	Slip-strike thrust fault	8.4	8.4	[1, 2]
23 July 1905	Severo-Khangayskaya, 370	Strike-slip thrust fault	8.7	8.7	[1, 2]
1906	San Andreas, 300	Shift	8.4	8.3	[1, 2]
27 June 1957	Muya, 30	Oppositely directed strike-slip normal and strike-slip thrust faults	7.9	7.9	[3, 4]
4 December 1957	Gobi-Altay, 270	Strike-slip thrust fault	8.6	8.6	[5]
5 January 1967	Mogodskaya, 45	Strike-slip thrust fault	7 3/4	7 3/4	[6, 7]
31 August 1968	Dasht-e-Bayaz, 25	Strike-slip normal fault	7.5	7.4	[8]

Note. Bibliographic references: 1 -- Voznesenskiy, 1907 (dimensions and types of seismodislocations more precisely defined); 2 -- Richter, 1963; 3 -- Solonenko, V., 1965; Kurushin, 1974; 4 -- Rothe, 1969; 5 -- GOBI..., 1963; 6 -- Pogrebinskiy, Chernyshev, 1974; 7 -- Earthquakes in the USSR, 1970; 8 -- Tchalenko, Ambraseys, 1970.

Table 2

Ratio Between I_0, M and K

I_0, балл (1)	Магнитуда (M) (2)							Энергетический класс (K) (7)				
	По Гутенбергу и Рихтеру, 1956* (3)		По Карнику и др., 1957 (4)		По Шебалину, 1957 (5)		По В. Солоненко** (6)	По Буне, 1962 (8)	По Медведеву, 1961 (9)		По А. Солоненко, 1973** (10)	
	1	2	H=10 км	H=20 км	H=10	H=20	H=20±5 км	H=10 км	H=10 км	H=20 км	K	M
6	5	4,6	$4^1/_4$	$4^3/_4$	$4^1/_4$	5	$4^1/_4$—$4^3/_4$	11—13	12	13	12	4,5
7	$5^3/_4$	5,1	5	$5^1/_4$	5	$5^3/_4$	$4^3/_4$—$5^1/_4$	13—14	13	14	13	>5,1
8	$6^1/_4$	5,8	$5^3/_4$	$5^3/_4$	$5^3/_4$	$6^1/_4$	$5^1/_4$—$6^1/_4$	14—15	14	14	14	>5,6
9	$6^3/_4$	6,4	6	$6^3/_4$	$6^3/_4$	7	$6^3/_4$—7	15—16	15	15	15	>$6^1/_4$
10	$7^1/_4$	7,1	$6^1/_2$	$6^3/_4$	7	$7^3/_4$	7—$7^3/_4$	16	15	16	16	7,3
11	8	7,6	$7^1/_4$	$7^1/_4$	$7^3/_4$	$8^1/_4$	$7^3/_4$—$8^1/_4$	16—17	—	—	17	8,2
12	$8^1/_4$	8,1	$7^3/_4$	8	$8^1/_4$	—	>$8^1/_4$	17—18	—	—	—	—

По Тошеру: $M = 5$, $I_0 = 6$—8; $M = 6$, $I_0 = 7$—8; $M = 7$, $I_0 = 9$—10; $M = 8$, $I_0 = 11$ (модифицированная шкала Меркалли)
(11)

Key:

1. I_0, force; 2. Magnitude (M); 3. according to Gutenberg and Richter, 1956*;
4. according to Karnik, et al., 1957; 5. according to Shebalin, 1957; 6. according to V. Solonenko**; 7. Energy class, K ; 8. according to Bune, 1962;
9. according to Medvedev, 1961; 10. according to A. Solonenko, 1973**;
11. According to Tocher: M=5, I_0=6-8; M=6, I_0=7-8; M=7, I_0=9-10; M=8, I_0=11 (modified Merkalli scale)

* - 1. M according to the data of the authors; 2 -- M, presented according to YeSSS.
** For earthquakes of the Mongolian-Baykal seismic belt.

Figure 10. Kvira Structure. South Slope of the Greater Caucasus. Photograph by V. P. Solonenko.

The ratios of I_0 and M (or K), according to different authors, are within the limits of accuracy of the analysis (see Table 2). Therefore the objections to the determination of the force of earthquakes by magnitude in the absence of corresponding macroseismic data in the epicenter are clearly meaningless. Nevertheless, these objections have been encountered in recent years when discussing the method of compiling the new seismic regionalization map of the USSR.

The force index remains and will remain for a long time the base for seismic regionalization for utilitarian purposes. For the enormous uninhabited areas or sparsely inhabited areas the determination of the intensity of earthquakes in the overwhelming majority of cases is possible only in terms of magnitude and seismodeformations for strong earthquakes.

CHAPTER II. STRUCTURAL-TECTONIC REGIONALIZATION OF THE PRECENOZOIC BASEMENT

The structural-tectonic regionalization of the southern part of Eastern Siberia (Fig 11) was carried out in accordance with the formational-structural and tectonic signs (time of formation of the structures, true composition, peculiarities of lithogenesis, metamorphism, magmatism, folding, position in the geostructural system and the sequence of the transition from the geosynclinal development to platform). The reader will find a detailed structural-tectonic description of the Baykal mountain regi in the paper by L. I. Salop (1967).

Region of Pre-Riphean Folding

In the southern part of the Siberian platform a most ancient folded basement is most completely represented in the territory of the Aldanskiy Shield. The outcrops of the pre-Riphean tectonic complexes on the surface, their geological structure and metamorphism indicate the complex heterogeneous structure of the lower platform stage, the greater part of which is covered under a thick mantle of slightly dislocated Paleozoic and Mesozoic series.

Aldan Shield

The age of the most ancient Aldan metamorphic complexes (the Iyengrskaya and Dzheltulinskaya series) is 2.640 billion to 2.340 billion years (TEKTONIKA YEVRAZII [Tectonics of Eurasia], 1966), which permits them to be paralleled with the saamides of other shields. The structures bordering the ancient nucleus on the west and south (the Olekma and Stanovoy zones, including the Kodaro-Udokan trough) belong to the Karelian phase of the folding, for the deposits of the Udokan series are penetrated by the synorogenic intrusions of the Kuandinskiy complex of granitoids (1.650 billion years).

Several stages have been isolated in the most ancient history of formation of the southwestern part of the Aldan shield. In the beginning the Aldan lithoplinth was formed (Dzevanovskiy, et al., 1968, 1970) made up of the early Archean formations of the Iyengrskaya and Dzheltulinskaya

series determining the later structural level of the Upper Archean complexes of the Stanovoy and Olekma zones. The platform stage of development of the Aldan shield itself, which was subjected to significant reworking during subsequent epochs of tectonic activation, began with the Lower Proterozoic. Thus, the western part of the investigated territory (the Kodaro-Udokan Region) served as the accumulation basin of the terrigenic-carbonaceous beds of the Udokan series during the Lower Proterozoic.

The plicative dislocations of the Aldan Shield have been sharply complicated by fracture tectonics. The largest faults enter into the system of the Stanovoy structural suture which extends hundreds of kilometers to the west and the east. It is controlled by the basite and ultrabasite intrusions, a wide band of diaphthoritic and cataclase rock, crushing and schist-formation zones. The development of the deep structural sutures and large dislocations with a break in continuity on each new level of tectonic activation was predetermined to a significant degree by the plan of the ancient faults, and frequently proceeded along the folded substrate not yet touched by the disjunctives. All of this together created a mosaic-block structure of the Archean basement, especially broken in the deep fracture zones.

Region of Baykal Folding

The folded structures of Baykalide in Eastern Siberia border the pre-Riphean Siberian platform on the south in arc separated from the latter by a system of marginal deep faults. They separate the Angara projection of the platform into two branches -- western (Sayano-Yenisey) and eastern (Baykal itself), joined together in the vicinity of the southern extremity of Baykal.

The Yenisey-Sayan Baykalide region forms a narrow strip extending along the southwestern edge of the Siberian platform. It is divided by the Bol'shoy Sayan fault into two tectonic zones. For one of them, the platform zone, block uplifts of the ancient Baykalide foundation are typical, and the other, the outer one, is a deep Riphean trough.

The occurrence and development of the Baykal geosynclinal took place in the marginal part of the Archean foundation of the pre-Riphean platform which was either partially broken and reworked or was involved in a powerful geosynclinal process. Correspondingly, in the modern erosion section, large and small blocks of reworked Archean rock, developed predominantly in the platform part of Eastern Sayan bounded on the southwest by the main Sayan fault, emerge at the surface.

The Archean structures inside the Baykal geosynclinal tectonic complex itself make up the Garganskaya block isolated at the beginning of the Proterozoic in the form of a stably uplifted block. Later, participating in the geosynclinal process, it separated the sedimentation basin into individual sublatitudinal troughs (Okinskiy, Il'chirskiy). The uplifted Garganskaya block was the nucleus of an anticlinorium.

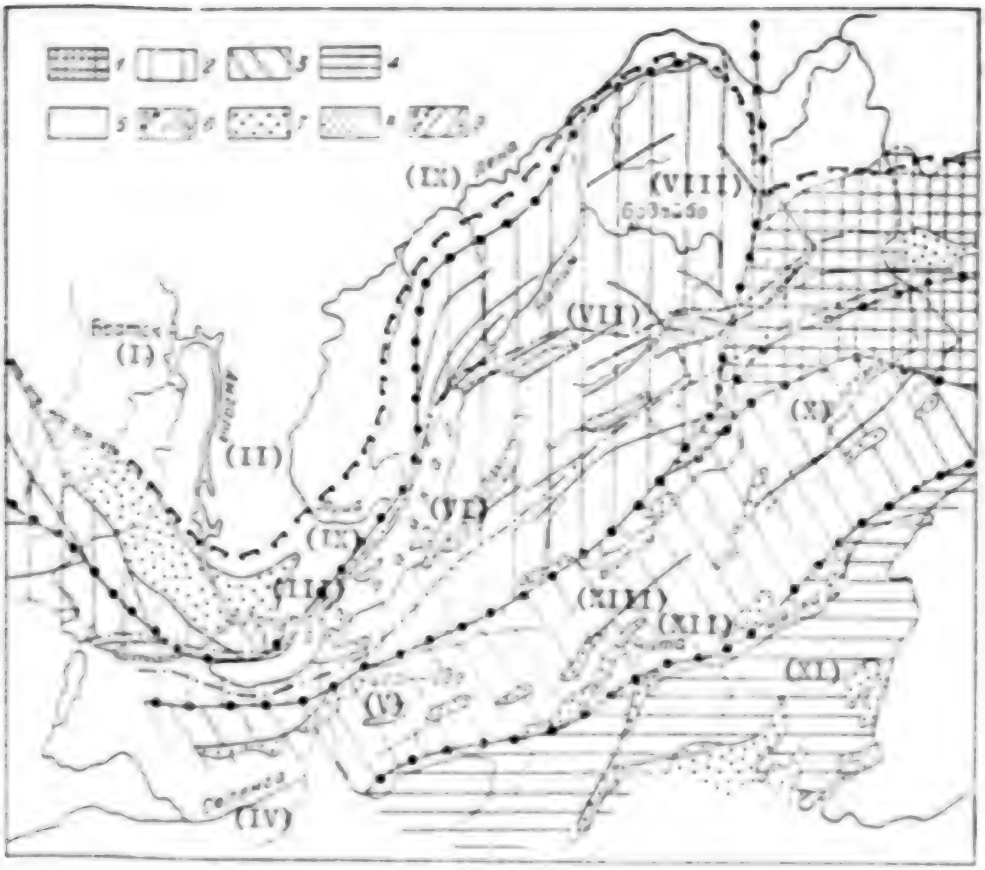

Figure 11. Schematic of the Structural-Tectonic Regionalization of the Pre-Cenozoic Basement of the Southern Part of Eastern Siberia.
Compiled according to data of A. L. Yanshin (1966) and T. N. Spizharskiy (1968)

1-4 -- region of folding: 1 -- pre-Riphean, 2 -- Baykal, 3 -- Caledonian, 4 -- Hercinian; 5 -- mantle of ancient and epiproterozoic platforms; 6 -- faults; a -- basic, deep, b -- other, undifferentiated; 7 -- Mesozoic basins and troughs; 8 -- main rift basins; 9 -- boundaries: a -- of the region of Mesocenozoic activization, b -- Baykal rift system.

Key:

I.	Bratsk	IX.	Lena
II.	Angara	X.	Olekma
III.	Irkutsk	XI.	Shilka
IV.	Selenga	XII.	Chita
V.	Ulan-Ude	XIII.	Vitim
VI.	Lake Baykal		
VII.	Vitim		
VIII.	Bodaybo		

The Baykalide complex was represented by metamorphic rock making up the two large synclinoria (Okinskiy, Il'chirskiy) and the Khamar-Dabanskiy anticlinorium. The set of Proterozoic effusive and sedimentary formations metamorphosed under the conditions of the green shale facies of regional metamorphism and reflecting a defined geotectonic regime will permit the consideration that here, in the ancient Archean foundation an independent geosynclinal system arose and developed.

The internal structure of the synclinoria is made up of symmetric anticlinals and synclinals; the overturned folds are observed only along the periphery or in contact with the Archean blocks. The general sublatitudinal plan of the folded structures sometimes is disturbed. This is explained either by the effect and the reworking of them by the Caledonian movements or the primary nonuniform orientation of the Proterozoic structures caused by the folded-block and block structure of the basement (Zavtsev, 1963).

The Khamar-Daban anticlinorium is made up of carbonaceous rock of the mica series, and the limbs were made up of gneiss of the Khangarul'skaya series. The hinge of the anticlinorium is undulating, wavy in plan view, with general sublatitudinal strike. Its limbs are made up of folds of higher orders having analogous orientation.

The Baykal zone encompasses the western and eastern Baykal region [Pribaykal'ye], the Baykalo-Patomskoye highlands and a significant part of the Stanovoy highlands.

The Archean basement protrudes in its modern structure in the form of several blocks bounded by faults -- Baykal, Muya Amalatskaya, and so on. The blocks are made up of gneiss-shale and carbonaceous-gneiss series with a total thickness up to 10 to 12 km (Frolova, 1962). Linear folds of predominantly northeasterly strike are characteristic for the Archean supercrystalline formation. The complication of the large folded forms by smaller ones (to microplication) and mass granitization of the rock is noted everywhere.

The geosynclinal complex of Baykalides is broken down into the outer miogeosynclinal and the inner eugeosynclinal zones (TECTONICS OF EURASIA, 1966). The former, in the form of a broad arc which is convex to the north, is located along the periphery of the Siberian platform. On the south it is bounded by a system of deep faults separating the Angara and the Aldan projections of the platform from the folded Baykalide system. In the north its folded structures continue possibly in the direction of the Vilyuskaya syneclise. In the outer zone, in addition to the already mentioned block projections of the ancient basement, a number of large folded structures are isolated: Necherskiy, Tonodskiy and Chuyskiy anticlinoria, Mamskiy, Bodaybinskiy and Pribaykal synclinoria.

The internal baykalide zone occupies the central zone of the Baykal mountain region, making up the broad, complexly constructed Barguzino-Vitim synclinorium. The side of the synclinorium is made up of a thick

(up to 12 km) set of basic effusives and their tuffs of spilite-keratophyre formation and metamorphosed shales, sandstones and limestones making up the lower structural stage. Lens shaped bodies of hyperbasite intrusives are connected with the faults of the pre-Baykal deposit separating the outer and inner zones.

Region of Caledonian Folding

In eastern Siberia, in accordance with the modern concepts (Yanshin, et al., 1966; Stizharskiy, et al., 1968), the strip of Caledonian structures borders the Siberian Baykalide region from the south (see Fig 11). The area of their propagation is bounded by the structural sutures -- Dzhidino-Vitim on the northwest and Mongolo-Okhotsk on the southeast.

Out of the two cycles of Caledonian folding development, early and late, only the former has found reflection here. The geosynclinal regime of early Caledonides begins to be exhibited from the Riphean, the completion of it takes place at the end of the Middle and beginning of the Upper Cambrian. Over the extent of the entire period, formations have occurred which are standard for early stages in the development of the geosynclinal regions.

The Caledonides of the investigated area can be divided with respect to structural-tectonic peculiarities into two parts: Sayano-Altay (Sarkhoyskiy synclinorium) and Trans-Baykal (Dzhida and Udino-Vitim synclinorium).

Sayano-Altay Zone

The lower Paleozoic structures are represented here by synclinal folds in the troughs which are complicated along the perimeter by upthrust faults and overthrusts. The sedimentary complex of the lower to middle Cambrian effusive-terrigenic and terrigenic-carbonaceous rock occurs on the erosion surface of the Proterozoic and Archean blocks.

The most completely Cambrian deposits are presented in the Sarkhoyskiy synclinorium where the total thickness of the geosynclinal complexly dislocated series is 6.2 km. Alongwiththe isoclinal and symmetric folds with steep (70-80°) limbs gently sloping folds are noted which are made up of flexures (Volkolakov, 1960; Arsent'yev, Volkolakov, 1964).

The lower Paleozoic folding stage turned out to be the final one. The tectonic structure, the set of formations, magmatism and metamorphism indicate that here the geosynclinal regimen ended in the pre-Cambrian time.

In the west the Sarkhoyskiy synclinorium is bounded by the Shutkhulayskiy uplift basically made up of the pre-Baykal metamorphic complex belonging to the region of Baykal folding (TECTONICS OF EURASIA, 1966).

Transbaykal Zone

Two subzones are isolated in the Transbaykal zone. One of them encompassing the basin of the upper course of the Dzhida River and the left bank of the Mongolian part of the Selenga River is represented by the structures of the Dzhida synclinorium made up of two stages of Wend-Cambrian deposits.

The central and edge parts of the synclinorium are made up of faults and folds of different order. First of all, this pertains to the southeastern limb which is connected with the proximity of the active zone of the bounding deep faults (Afanas'yev, 1973).

Simple linear folds, in places isoclinal and overturned, participate in the internal formation of the synclinorium. The centriclinal closure is complicated by a deep fault with northeasterly strike. In the axial part of the synclinorium a central anticlinal is isolated which runs from the borders of the USSR with Mongolia to the central course of the Darkhituy River. The geosynclinal development of the Dzhida subzone itself ended in the Middle Cambrian.

In the east the Dzhida synclinorium becomes the Udino-Vitim (the second subzone) through the basement protrusions. Its boundary runs along the southeastern slopes of the Khamar-Daban ridge: the Vitimkan and the Tsipikan Rivers on the northwest and the central course of the Chikoy, Ingoda and Tungir Rivers on the southeast. Similarly to the Dzhida, it occurs on the broken pre-Cambrian foundation, individual blocks of which have been retained in the internal geoanticlinal uplifts (Zaganskoye, Yablonovoye, Malkhanskoye, and so on).

Hercinian Folding Region

On the Tectonic Map of Eurasia, the region located southeast of the Mongolo-Okhotsk structural suture (see Fig 11) is all considered to be part of the eastern Siberian hercinides. However, in the description of the map it is stipulated that this region has mixed structural features, and the problem of whether it should be classified among the hercinides or mesozoides cannot be considered finally decided (TECTONICS OF EURASIA, 1966).

The geosynclinal complexes of the lower structural stage of the hercinides began to be formed in the Ordovician or Silurian, and the end of their formation belongs to the middle or the tops of the Middle Devonian (TECTONICS OF EURASIA, 1966). Beginning with the Devonian and, approximately, to the upper Carboniferous (in the Aginskiy trough to the Lower Triassic), the complexes of the upper structural stage were formed.

In the troughs where the hercinides are deposited, there are silicide-terrigenic and terrigenic formations; in the uplifts, they are supplemented by volcanogenic, volcanogenic-plutonic diorite-granite and intrusive granodioritic complexes

The folded series in the outlines of the hercinian geosynclinal are detected in the Zachikoyskiy, Daurskiy, Aginskiy and the Priargunskiy Rayons.

A thick (6-7 km) sand-shale Zachikovskaya series of pre-Permian age has developed in the Zachikovskiy Rayon. With respect to formations it is similar to the Central Paleozoic formations of the Aginskoye field and northeastern Mongolia. The rocks of the Zachikoyskaya series are in places penetrated by granites 395 million to 425 million years old, which indicates the possible presence in its composition of Lower Paleozoic rock (Kosygin, 1965). In the bottoms of this series the polymictic sandstones predominate. At the top of the section they are replaced by conglomerates and striated shales. The largest folded forms here are the Aginskiy anticlinorium and the Chikokonskiy synclinorium.

A characteristic feature of the Aginskaya structural-formational zone is the fact that here the geosynclinal regimen has been retained until the Permian to Central Triassic (Amantov, 1963). In the Upper Paleozoic to Lower Mesozoic, thick (more than 5 km) series of terrigenic sediments have accumulated: aleurolites, polymictic sandstones with lenses of conglomerates and argillaceous shales. The rocks are crushed into linear folds of different order. Intensive plication and razval [disintegrated blocks piled up on mountain slopes] formation have developed in them, and numerous extended fractures are observed (predominantly overthrusts and shifts).

In the Daurskiy synclinorium, the section of the sedimentary series differs somewhat from the adjacent accumulation regions. Here carbon-quartz-sericite shales (in the lower section) and schistose polymictic sandstones (in the tops) are isolated. In addition, interlayers and lenses of greenstone metaeffusives of basic and medium position are encountered in the section. The total thickness of the deposits is to 5 km (Gorzhevskiy, and so on, 1970).

The Priargunskaya geosynclinal zone is predominantly made up of large-clastic deposits and limestones. Sometimes acid tufogenic rock is encountered among them. The apparent thickness of the deposits is more than 2 km. In the basement rocks they occur with sharp angular mismatch. A brachyform nature is characteristic of the folded structures of this zone.

The hercinide section is crowned by proterogenic continental or marine melasse and granodioritic Permian-Triassic formations (Zonenshayn, 1967). With respect to their lithologic attributes they are very similar to the hercinide sections of many other regions of the eastern part of Central Asia. On the other hand, similarity of them to the geosynclinal sections of some of the mesozoide regions of northeastern USSR is detected. The most characteristic in this respect is the Priargunskaya zone where in recent years small fields of marine Upper Triassic and Lower Jurassic deposits were detected. This has permitted some researchers (TECTONICS

OF EURASIA, 1966) to consider the given region as a transitional structural region between typical hercinides and mesozoides.

Region of Mesozoic Activation

The Mesozoic tectonic-magmatic activation has encompassed an enormous area: the peripheral part of the ancient Siberian platform, the regions of pre-Riphean Baykal, Caledonian and Hercinian folding and southeastern Transbaykal where up to the Upper Mesozoic obviously the subgeosynclinal regime was retained which was caused by the effect of the Mongolo-Okhotsk synclinal belt.

The evolution of the mesozoic structure is presented in the following form. Since the end of the Upper Triassic, large arches have been formed -- the Sayano-Baykal arch and the Yablonovo-Stanovoy arch (Bogolepov, 1967) -- or a single arched uplift (Koreshkov, 1960). In the Middle and Upper Jurassic, the differentiation of the movements has led to isolation of the folds with large radius of curvature: the Sayano-Stanovoy outer and Khentey-Daurskiy inner belts of block uplifts, the Selenga-Vitim zone of relative subsidence (Arsent'yev, 1967), the Irkutsk and Chul'man foothill coal-bearing troughs (Salop, 1967). In the Upper Jurassic to the Lower Cretaceous, differentiation of the block movements are intensified, which promoted the formation of numerous intermontane basins and block anticlinals (Ivanov, 1949).

The Middle Jurassic volcanogenic-sedimentary rock of the Selenga-Vitim zone of relative subsidence are made of acid effusives (felsites, felsite-porphyries, porphyrites, quartzitic porphyries, and so on), tuffs, tuffoconglomerates, large block conglomerates, gravelites, aleurolites and argillaceous shales. The series are usually metamorphosed: chloritization and silicification appeared in the effusives, and argillaceous shales were converted in places to quartz-mica shales. The deep analogs of the effusives in this age are the subvolcanic formations: microdiorites, dioritic porphyries, diabase porphyries, alaskites, granosyenites, and so on.

Inside the western, eastern Sayan part of the outer belt of the block uplifts with block differentiation, a group of Urda-Oka grabens was formed. They are bounded on all sides by the fractures of the Main Sayan System. Here the Middle Jurassic deposits are separated into the Naringol'skaya series (Florensov, 1968) with a total thickness to 2.5 km made up of breccia, conglomerates, sandstones, aleurolites, carbonaceous argillites, gravelites covered by coarsely-clastic conglomerates and fanglomerates. The rock is intensely dissociated. Near the fractures bounding the grabens and making up their internal structure, overturned folds are observed. On the whole, simple synclinal folds predominate here (Basharina, 1973).

In the Central Jurassic time, eastern Sayan served as the basic supplier of clastic material for filling the depressions of the Irkut amphitheater. The south edge of the latter was at that time a foothills trough which occurred at the junction of the pre-Mesozoic folded structures of the Baykal (northeastern) and Sayan (northwestern) directions. The principal age of sedimentation -- the Middle Jurassic -- was preceded by the formation of the basal series from 50 to 300-400 meters thick. The amount of coarsely clastic material increases to the south. The sand-aleurolite horizons contain numerous coal beds. In the southern part of the Irkut amphitheater a combination of two troughs of Sayan and Baykal orientation converging at right angles is noted. The Mesozoic synclinals frequently coincide with the analogous forms of the Lower Paleozoic. Here the former are more gently sloping and are somehow embedded in the latter. The dip angles of the Jurassic layers on the limbs of the synclinals reach 20 to 25°.

The Chul'man trough is located in the basin of the upper course of the Aldan. Structural-geological complexes of the Jurassic and Lower Cretaceous have developed here which make up both the Chul'man basin and the system of grabens containing it to the east (the Kudulinskiy, Khaniyskiy) and the relict Mesozoic depressions of the Kodaro-Udokan Region.

The western end of the Chul'man basin was represented by the Nizhnetungurchinskiy or Usmunskiy trough (Dankevich, 1969). It was executed as a thick series of continental coal-bearing deposits (Mokrinskiy, 1961, 1962; Mironyuk, et al., 1971). On the whole, with respect to composition they are alike and are made up of rhythmically alternating conglomerates, gravelites, sandstones, aleurolites and argillites with interlayers of coal almost completely compensating for the troughs; clearly expressed geologically, it is weakly manifested in the modern relief which makes it similar to the type of inverted structures. The total thickness of the Jurassic sediments is 1350 to 1500 meters (Ishina, 1961), and with respect to geophysical data, 4.5 km (Mikunov, 1965; Dankevich, et al., 1970).

By the end of the Middle Jurassic the volcanogenic formation gradually is replaced by the coal-bearing formation. The conditions of sedimentation in the Upper Jurassic age were favorable almost everywhere. In Trans-Baykal, the coal-bearing Gusinoozerskaya series was formed in the Upper Jurassic to Lower Cretaceous 1.2-2 meters thick. At the same time, conglomerates, sedimentary breccia, gravelites, sandstones with interlayers of aleurolites, argillites, carbon-argillaceous shales and coals were accumulated in the northeast.

The formation of the Mesozoic structures was a direct consequence of the wavy distortion of the earth's surface with the formation of parallel swells (arches) and subsidence belts between them. The slow wavy bending (surface folding) was initial, but not decisive, for the faults and bends hang on each other and follow one out of the other (Florensov, 1954).

In the example of several of the basins N. A. Florensov (1960a) comprehensively investigated the basic structural peculiarities and derived some general laws of their development. In the majority the basins are synclinal basement troughs compensated for by thick sedimentary series. They are not symmetric either in structural or in facies respects. The bottoms of the troughs were almost flat and level, and the maximum depressions are somewhat shifted to one side. The marginal faults are noted along both sides of the basins. Many of the faults have had an active influence on the course of sedimentation in the Upper Jurassic to Lower Cretaceous time. The transverse faults had great significance in the postsedimentation period. The overthrusts occurring in the latest stages of Mesozoic activation possibly occurred from the more ancient faults. All of these structural-geological peculiarities are characteristic of the majority of Trans-Baykal basins.

Basic Abyssal Fractures

The natural boundaries between the regions of the Saam, Karelian, Baykal and Hercinian folding are usually the large zones of abyssal fractures extending 800 to 1000 km (the Main Sayan, Stanovoy, and so on) to 2500 km or more (Mongolian-Okhotsk). As a rule, they are accompanied by thick (to tens of kilometers) zones of tectonically reworked rock, large and small basite and hyperbasite intrusions, the centers of volcanic eruptions, gravitational steps usually depicting discontinuous variation in thickness of the earth's crust and characterizing the great depth of penetration of them into the depths of the earth.

The time of occurrence of deep fractures is determined by the age of the geosynclinal systems developing in the edge parts of the formed platforms (epiarchean, epibaykal, and so on). Over the extent of all of the subsequent ages of tectogenesis, these linearly extended structural sutures were the most mobile and penetrable sections of the earth's crust. A high degree of fracturing of the rock and intensive metamorphism of it are characteristic of them. In addition, the deep fractures are accompanied by a dense network of contiguous subparallel and feathering fractures of different genetic type (faults, strike-slip normal faults, overthrusts, and so on), and also the depressions next to the fractures in which relicts of the Paleozoic and Mesozoic deposits were retained. The genetic variety of dislocations with a break in continuity in the abyssal fracture zones is caused by variability of the tectonic stress fields with time. Accordingly, the ages of predominant development of the upthrust faults and overthrusts were replaced by ages of fault formation. The role of the shifts remains unclear to the present time.

The Stanovoy abyssal fracture extends 800 to 900 km from the Vitim River in the west to the Dzhugdzhur ridge in the east. Over the entire extent it is accompanied by thick zones of various tectonically reworked rock, large and small intrusions of basite-hyperbasite composition, depressions of different age and fields of Cenozoic basalts (Kazmin, 1962). The

fracture bounds the ancient nucleus of the Aldan shield from the south and includes a section between the Chul'man overthrust, the Stanovoy and Yuzhno-Stanovoy abyssal fractures in the investigated territory. According to the geophysical data, a zone has been established here with a density deficit of no less than 0.1 g/cm^3 with respect to the encircling sections of the shield and the Upper Archean folded region. It extends up to 10 km in depth with a width from 25 to 80 km. This zone can be caused either by local dispersion of the Archean complex of the shield as a result of the granitized rock, granites, diafluorites or thickening of the earth's crust connected with its bending under the effect of the overthrust of the Stanovoy region onto the ancient nucleus of the Aldan shield (Dankevich, et al., 1969, 1970).

The Main (Greater) Sayan Fracture extends 1000 km from the southern extremity of Lake Baykal to the northwest (300-310°) almost to Krasnoyarsk. In the modern denudation section it is a system of fractures with powerful zones of crushing, jointing and mylonitization. All of the rock from the Archean to the Paleozoic inclusively were subjected to dynamometamorphic reworking. The basic "trunk" of the fault is accompanied by numerous subparallel, longitudinal and feathering fractures of sublatitudinal (270-290°), submeridional and northwestern (330-350°) strikes. The entire system of fractures from 5-6 to 8 km wide (Smirnov, et al., 1969; Berzin, 1967), and in some places up to 30 km, forms a characteristic "horsetail." Small hyperbasite bodies, basic rock dikes and numerous granitoid intrusions of different age are associated with the fracture zone.

The occurrence of the fracture belongs to the Late Archean to the beginning of the Proterozoic, and the subsequent shifts were manifested more than once to the present time. The analysis of the structures in the vicinity of the Main Sayan Fracture and its walls leads some researchers (Arsent'yev, 1965; Musatov, 1964; Berzin, 1967; et al.) to the conclusion of the participation of horizontal differently directed (along with vertical) displacements along the fracture. Being the boundary of the structural-facies zones, as the aeromagnetic research has demonstrated, a fracture separates the differently oriented linear magnetic anomalies. The magnetic field of the fracture is characterized by a narrow, linearly elongated zone of sign-variable anomalies and large gradients (Musatov, 1963). With respect to the gravimetric data, the fracture has an inclination of the displacer plane to the southwest at an angle of $55 \pm 5°$. The roof of the basaltic layer southwest of the fracture occurs at a depth of 14 km, and northeast, 8 km. Thus, the fracture is interpreted as a fault with an amplitude of about 6 km (Moiseyenko, 1969).

Pribaykal Fault

In the western and southwestern Baykal region [Pribaykal'ye] the system of abyssal fractures separating the ancient Siberian platform from the folded structures of the Baykal mountain region framing it on the southeast,

becomes part of the Obruchevskiy fault system. It is also known under the name of the Pribaykal fault (Salop, 1967) or the Baykal marginal suture (Yegorov, 1971). It extends 1300 km. In the opinion of certain researchers it began to be formed in the Archean (Zamarayev, 1961), and according to others, in the Lower Proterozoic (Salop, 1967). The fault outlines the platform from Southern Baykal to the Patomskoye Highland and predetermines the orientation of the geosynclinal system of baykalides adjacent to it.

The system of faults of the Baykal marginal suture obviously is reflected in the structure of the geophysical fields. In the magnetic field it is obvious with respect to the linearly striated anomalies. The radioactive field in the fracture zones is high, and the gravitational field, on the contrary, as a rule, is low. The suture boundaries are most clearly expressed in the radioactive field by replacement of the level and structure, and in the magnetic field, in addition, by variation of orientation of the anomalies (SEISMOTECTONICS..., 1968; Yegorov, 1971).

In western Pribaykal'ye, the presence of a marginal suture is well confirmed by deep seismic probing. In all the seismic sections intersecting the Baykal basin, crosswise from the Selenga River delta to the headwaters of the Lena, an abyssal fracture has found reflection which extends along the west bank of the lake. It has a vertical dip and runs below the Mokhorovich divide. At the intersections of the southwestern side of the basin, a scarp-like uplift of the mantle surface in the direction of the lake with an amplitude of 3 km is noted (Puzyrev, et al., 1973).

The Dzhidino-Vitim abyssal fracture (structural suture) is extended in the northeasterly direction from the boundary with Mongolia in the vicinity of the upper course of the Dzhida River, along the Uda and Vitim Rivers and then along the Kalar River. It obviously runs to where it joins with the Yuzhno-Aldan marginal suture. Its total extent in this direction is more than 1000 km with a width from 5-10 to 50-60 km (Arsent'yev, 1965).

The beginning of the formation of the fracture pertains to the time of completion of the Baykal folding and the beginning of the manifestation of the Caledonian folding, that is, it serves as an interface between the two regions of appearance of the folding of different age. In structural respects the suture is represented by echelon arranged fractures with which the breccia zone, the zones of cataclase, mylonitization and cleavage of rock of different age beginning with the pre-Cambrian are connected.

According to the geophysical data (Arsent'yev, 1965), the fault bounds the magnetic and gravitational fields which differ sharply with respect to nature and intensity.

The Mongolo-Okhotsk abyssal fracture (Gorzhevskiy, Laz'ko, 1961) is a suture zone from 5-20 to 60-80 km in width extending more than 2000 km within the boundaries of the Soviet Union (Misnik, et al, 1969). The fault runs from the border with Mongolia along the Chikoy, Ingoda,

Shilka River valleys and then to the northeast to the shores of the sea of Okhotsk. Along almost the entire extent, the fracture is the interface between the Hercinian and Caledonian folded structures (see Fig 11). Its occurrence belongs at least to the Late Pre-Cambrian. The formations of the Late Pre-Cambrian and the Early Paleozoic in the Mongolo-Okhotsk fracture zone are represented by greenstone, ophiolitic formations (Zonenshayn, 1967).

The depth of the fracture and the duration of its existence are emphasized by the relation to it of numerous massifs of intrusive rock of different composition and age. The sharply elongated massifs of Upper Mesozoic gabbro-diorites and monzonites, Late Lower Cretaceous granitoids and Paleogenic basalts.

According to the data from deep seismic probing (Bulin, et al., 1972), the fracture zone coincides with the sections of the sharp scarps in the surface relief of Konrad and Mokhorovichich. The amplitude of the scarps of the Konrad boundary reaches 3 to 6 km.

In conclusion, of course, we must answer the following question: do the structural-tectonic elements of Eastern Siberia have any effect on its seismicity, and can the historical-structural analysis be used under our conditions (Petrushevskiy, 1965) even for the general determination of the seismic potential of the large structural-tectonic regions?

On the whole, the answer is found to be negative. It is unique but it is possible when determining the seismic potential of the pre-Cenozoic structures to use the fact that this is in practice aseismicity of the greater part of the region of development of the Siberian platform mantle, but strong shocks often occur here (M to 5.2, K=13). Another element of the Siberian platform -- the Aldan shield (a region of pre-Riphean folding, see Fig 11) -- in its different parts has seismic potential almost from 0 to M=7.9, possibly even more. The same thing can be said of the region of Baykal folding. We are not talking about the rift zone as a specific neotectonic structural element, but other parts of the baykalides, with like mesocenozoic rejuvenation, uniform with respect to its seismicity: from aseismic (Vitim Plateau, part of the Northern Baykal Highlands) to force 9 or more (Eastern Sayan).

The zone of Caledonian folding over its greater part is almost aseismic, and only in the region bordering on Mongolia are there individual epicenters of modern earthquakes, but then to the west, in the territory of Mongolia, its activity increases quickly and reaches maximum values (to M=8.7) although with respect to external manifestations the Cenozoic activation in the entire zone is essentially light and all the more so in the seismoactive part it is quantitatively less expressed than in certain in practice aseismic region.

The same thing can be said of the region of hercine folding. In the extreme northeast (Shilkinsko-Argunskiy Rayon) only rare earthquakes are

known with M to 4-1/2. Then stretching 650 km to the southwest, only individual epicenters of weak earthquakes are known. On the Daurskiy Ridge there is a flaccid epicentral field with earthquakes of modern intensity (to force 7, M to 5-1/4). In the territory of Mongolia, the seismic activity of this region quickly increases on moving to the west, and the magnitude of the earthquakes reaches 7-3/4 (Mogodskoye earthquake on 5 January 1967), and with respect to paleoseismogeological data, to 8.

The seismic potential of the abyssal fractures is not uniform. The various parts of Obruchev, Mongolo-Okhotsk and other fractures are in practice now aseismic and now they have limiting seismic potential (earthquakes or traces of preseismostatistical earthquakes with M to 8.7).

The structural-tectonic level has no defined effect on the spread of the tremors. If the level of high-force (force 8 and higher) isoseisms is subordinate to the level of seismogenic structure, then the subsequent isoseisms extend now along and now across or diagonally to the structures visible on the earth's surface. Previously the existing concept of regular orientation of the isoseisms in the Sayan (Northwestern) and Baykal (Northeastern) directions was not confirmed although for individual earthquakes the isoseismal fields as a whole or individual sections of it turn out to be extended along the regional structural fields.

The real composition of the geological complexes is felt more definitely in the spread of the seismic oscillations. The decisive predominance of the seismically active regions of dense crystalline rock causes weak damping of the moderate (less than force 8) seismic tremors which extend to significantly larger areas by comparison with seismic zones made up of thick series of sedimentary or volcanogenic-sedimentary rock (Central Asia, the Caucasus).

It is natural that under favorable conditions the seismogenic movements are using the existing weakened sections of the earth's crust independently of their age, including the transverse and diagonal fracture zones of ancient occurrence which are isolated in greater amount in accordance with the detailing of the geological and especially the geophysical research. However, it is quite definitely obvious that the seismogenic movements with respect to the ancient structures take place only as a function of the modern seismotectonic processes, and the latter are genetically independent of the ancient structures.

CHAPTER III. BASIC CHARACTERISTICS OF THE LATEST STRUCTURE

The Cenozoic tectonic activation in the southern part of Eastern Siberia was preceded by a comparatively long (Upper Cretaceous to Paleogene) tectonic interval during which the denudation planation surface was formed. The development of the large latest structural forms (in particular, the rift basins) began with the end of the Paleogene to the beginning of the Neogene. In the Middle Pliocene, the intensity of the tectonic movements increased sharply. However, the increase in rate of movement was not accompanied by radical rearrangement of the structural plan. Therefore for solving the general problems of genesis of the latest structural forms it is admissible to consider them as the final result of the deformation of the basic (Upper Cretaceous to Paleogenic) planation surface. The mapping of this surface presents known difficulties and it requires special geological and geomorphological studies. Unfortunately, these studies were made in far from all of the areas of the investigated territory.

The approximate representation of the modern position of the deformed initial planation surface in the uplift regions can be given by the imaginary surface enveloping the mountain peaks. It is possible to construct this "peak surface" by sufficiently detailed topographic maps considering the geological materials. In the basins, the basic planation surface is buried under the Cenozoic deposits. If the precipitates are not thick (the basins of the Transbaykal type and certain small basins of Pribaykal'ye), the approximate representation of the structure of such depressions can be given by a smooth sedimentary surface relief. If the thickness of the deposits is large, then for analysis of the latest structure it is necessary to use the geophysical materials. The large basins of the rift zone have been most completely investigated by the gravimetric method. The quantitative interpretation of the negative local gravitational anomalies observed over these basins combined with the electrical prospecting data, seismic prospecting and drilling offers a representation of the relief of the crystalline bed under a powerful series of weakly lithified continental deposits.[1]

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[1] A procedure for interpretation of the geophysical data with respect to basins, just as the procedure for constructing the "peak surface" in the uplift regions was discussed in the monograph by Yu. A. Zorin (1971).

In the schematic of the latest structure compiled by these methods (see Fig 12), isohypses of the deformed planation surface are depicted which offer the possibility of quantitative estimation of the amplitudes of the vertical tectonic movements. The faults that are active at the latest time are depicted in the diagram. The faults have greater amplitude, they are well exhibited in the planation surface scarps. The faults with small displacements are plotted on the map according to the geological data (ACTIVE TECTONICS..., 1966; SEISMOTECTONICS..., 1968).

The southern part of Eastern Siberia is divided into the following regions with respect to degree of manifestation of the latest movements: the Sayano-Baykal intensive mountain formation, the Transbaykal moderate mountain formation and the Siberian platform (the region of weak mountain formation).

Sayano-Baykal Region of Intensive Mountain Formation

In the investigated territory its greater part enters into the Baykal rift zone extending almost 200 km from the vicinity of the Khubsugul'skaya and Darkhatskaya basins in the territory of Mongolia to the vicinity of the Tokkinskaya basin in Southern Yakutia. Here we are talking about the region of development of the standard, morphologically well expressed rift structures. Obviously it is necessary to include the high mountain ridges separating and surrounding the basins in the rift zone. With this interpretation, in structural respects it coincides with the greater part of the Sayano-Baykal arch uplift isolated by Ye. V. Pavlovskiy (1948b).

The average width of the Sayano-Baykal arch uplift is 200 km. The tops of the ridges entering into it reach 2000 to 2500 meters with respect to the most stable internal parts of the Siberian platform. The arch uplift is nonuniform with respect to its strike. It is divided into three parts by transverse reduced peak surface: Eastern Sayan (to the lower course of the Selenga River), Baykalo-Barguzin (from the Selenga River to the submeridional section of the Vitim River Valley) and Kodaro-Udokan.

The rift zone borders the Siberian platform only in its midsection (with respect to strike). In the southwest of the northeast it is separated from the platform by the transitional structures -- the shield type uplifts: Prisayanskiy and Baykalo-Patomskiy (Solonenko, V., 1968b).

The large rift depressions usually have a length of 150 to 200 km and a width of 35 to 45 km. The Baykal depression extends to 670 km with an average width of 40 to 55 km (maximum, 70 km). The interbasin commissures usually are characterized by lower altitudes than the uplifts surrounding them. Therefore the basins are joined together, forming extended branching rift valleys. Thus, the Baykal basin is joined to the Tunkinskaya, the Upper Angara and the Barguzin basins, and the Chara basin is joined with the Muya and the Tokko Basins.

The Baykal basin is divided by the diagonal uplift of the Academic Ridge into the southern and northern basins. Judging by the gravimetric, seismological and electroprospecting data, the thickness of the Cenozoic continental deposits in the first basins reaches 7000 meters (the vicinity of the Selenga River delta), and in the second basin, 4500 meters (the vicinity of the mouth of the Upper Angara). The absolute elevations of the crystalline bed in these areas drop to -6500 and -4000 meters, respectively.

In the other large rift basins (Tunkinskaya, Barguzin, Upper Angara, Lower Muya and Chara) the thicknesses of the Cenozoic deposits reach 2300 to 2800 meters, and the absolute elevations of the basement surface, drop to -1500 to -2000 meters. These thicknesses are characteristic of the internal basins which with respect to strike are separated by the saddle commissures in which the thickness of the sediments usually decreases by 2 or 3 times. There are many cases where within the limits of the saddle commissures the basement rock is denuded on the earth's surface (the Tunkinskaya basin). The age of the sediments filling the large rifts is from the Oligocene to the Holocene, inclusively.

The altitudes of the denudation planation surface to the beginning of the latest activation obviously can be estimated at 300 to 600 meters. Consequently, judging by the modern hypsometry of this surface, the uplift of the Baykal arch and the subsidence of the basement in the large rift basins are absolute and not relative. The full scale of the vertical movements in the rift zone will reach 5000 to 6000 meters, and in the vicinity of Lake Baykal, even 8000 meters.

In addition to the above-enumerated basins, quite broad negative structural forms with respect to area with comparatively small thickness of the Cenozoic, Neogenic and Quaternary sediments are encountered within the boundaries of the rift zone. These slowly developing structures include the Bauntovskaya and Tsipikan basins in which the thicknesses of the Cenozoic deposits do not exceed several hundreds of meters.

Comparatively small negative structural forms are also developed in the rift zone: embryonic basins and basins being born (Solonenko, V., 1968b). The former have a length on the order of several tens of kilometers with a width to 5 km. The thickness of the precipitates (predominantly Quaternary) in them is 100-200 m. The basins being born have begun to be formed at the end of the Pleistocene and in the Holocene. Their length is less than 10 to 15 km, the width to 0.5 and 1 km, depth from several meters to 100. The sedimentation in such basins is in the initial stage (Solonenko, V., 1968b).

A characteristic feature of the majority of large rifts (basins of the Baykal type) is unique asymmetry of the transverse cross sections: their northwesterly and northern sides are the larger. For the Baykal, Tunkinskaya Barguzin and Chara basins, this characteristic has been established

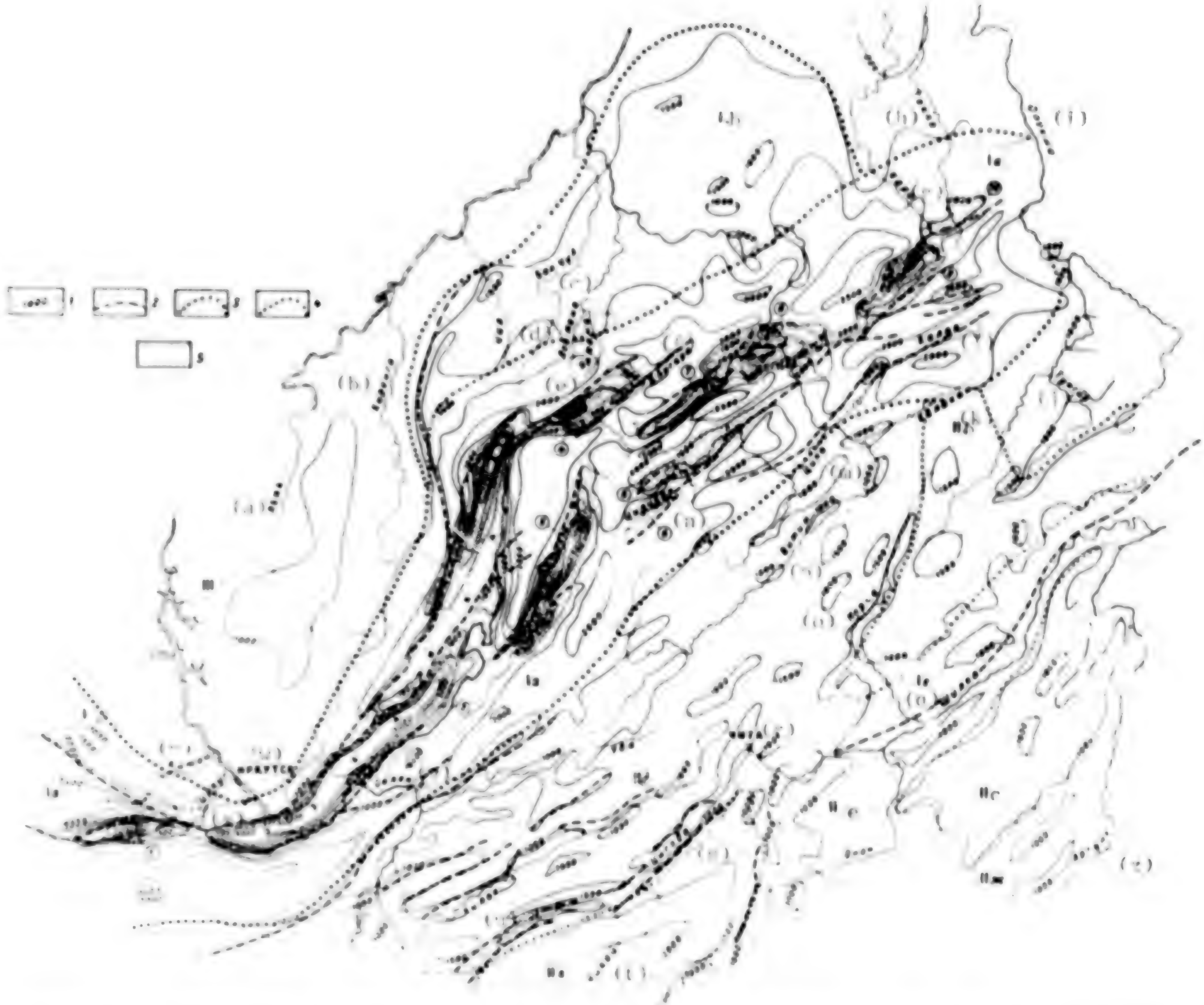

Figure 12. Schematic of the Latest Structure of Eastern Siberia. Compiled by Yu. A. Zorin, L. V. Bogatova, M. R. Novoselova

[See legend on p 78]

[Legend to Fig 12, p 77]:

1 -- isohypses of the Upper Cretaceous to Paleogenic planation surface deformed by the latest movement; 2 -- fault; 3 -- boundaries of the neotectonic regions; 4 -- boundaries of the structural zones; 5 -- areas of rift basins. The numbers on the left are as follows: I -- Sayano-Baykal region of intense mountain formation, including the Baykal rift zone (Ia), Baykalo-Patomskoye (Ib) and Prisayanskoye (Ic) shield uplifts; II -- Transbaykal region of moderate mountain formation, including Daurskoye (IIa), Olekma-Stanovoy (IIb), Undino-Gazimurskoye arch uplift (positive structure) zones (IIc), Vitim-Selenga (IId), the Aga (IIe), Prishilka (IIf) and Priargunskaya (IIg) negative zones; III -- Siberian platform; 1-7 rift basins: 1 -- Tunkinskaya; 2 -- Baykal; 3 -- Barguzin; 4 -- Verkhneangara; 5 -- Tsipinskaya; 6 -- Tsipikar 7 -- Upper Muya; 8 -- Lower Muya; 9 -- Chara; 10 -- Tokko.

Key:

a. Lena	l. Kalar	w. Irkutsk
b. Kirenga	m. Tsipa	x. Irkut
c. Bol. Chuya	n. Tsipikan	y. Kitoy
d. Left Mama	o. Nercha	z. Argun'
e. Right Mama	p. Vitim	
f. Upper Angara	q. Shilka	
g. Chara	r. Chita	
h. Tokko	s. Ingoda	
i. Olekma	t. Chikoy	
j. Tungir	u. Khilok	
k. Kalakan	v. Selenga	

previously by the geomorphological and geological data. The interpretation of the geophysical measures demonstrated that the inner troughs of the Lower Muya [Nizhnemuyskaya] basin and the Kocherskaya trough of the Upper Angara basin have the same "Baykal" asymmetry.

The like asymmetry of the large rifts is connected with the fact that the large-amplitude faults are coordinated predominantly with their northwestern and northern sides. Usually at these points not one fracture is noted, but the entire series of complexly branched fractures of the basement. The amplitude of the individual faults reaches 1500 to 2000 meters, and in the case of the Obruchev fault bounding the southern Baykal trough from the northwest, even 3000 to 4000 meters. It must be noted that the presented values are 2 to 4 times smaller than the overall scale of the vertical movements.

On the southeastern sides of the large basins the discontinuous dislocations play a significantly smaller role. Here their vertical amplitudes usually do not exceed the first hundreds of meters, and they disturb the general picture of the gradual increased thickness of the Cenozoic deposits toward the axial parts of the depressions little. In the transverse cross section

the surface of the crystalline basement of the large basin is described by the gently sloping arches which are convex downward which are complicated only in individual places by fault scarps. Thus, the geodetic data confirm the opinion of M. A. Florensov (1960) on the constant combination of discontinuous and plastic dislocations of the basement in the structure of the large basins of the Baykal type.

The development of the rift zone was nonuniform. In the Oligocene to Early Pliocene, the rate of downwarping of the sections of the large basins (the sedimentation rate) was 0.07 to 0.17 mm per year (Zorin, 1971). Judging by the nature of the clastic material, it is possible to assume that the rate of rise of the adjacent uplifts was also small, and the short geomorphological scarps in the framing of the basins were absent (Logachev, 1968). Obviously the predominant style of deformation of the basement at that time was elastic.

In the Middle Pliocene to the Quaternary period in the large rift basins the downwarping rate increased to 0.3 to 0.5 mm per year (Zorin, 1971). The submersion of the clastic material of the sediments indicates an increase in altitude of the mountain ridges and the degree of their dismemberment. From the Middle Pliocene the relief is similar with respect to type to modern (Logachev, 1968). Within the boundaries of the large basins an important role has come to be played by the fault scarps. Obviously the rate of rise of the uplifts was with respect to its order comparable to the rate of downwarp of the bottoms of the large rifts.

The increased seismicity of the rift zone indicates its high modern tectonic activity. The presence of correlations between the seismicity and certain geomorphological and geophysical parameters reflecting the latest structure[1], permits us to consider that in modern movements the basic trends of its neotectonic development are retained: the formation, submersion and expansion of the rift basins against a background of general arch uplift of the territory.

The eruptions of the effusives of basic composition are connected with the latest tectonic movements in the Baykal rift zone. The volcanic activity in the southeastern and the central part began at the end of the Oligocene, and in the northeast, at the end of the Pliocene (ACTIVE TECTONICS.... 1966) and continued with interruptions to the Holocene.

The relation of the volcanism to the latest tectonics is expressed only in most general form (Florensov, et al., 1968). The fields of effusives usually are not coordinated directly with the large rift valleys. The Tunkinskaya basin constitutes an exception, at individual locations of which interstratification of the sedimentary formations with the basalts

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[1]See Chapter IX.

is observed. However, in this area (Sayano-Khamardaban effusive field) the basalt covers and pyroclastic formations extend far beyond the limits of the depression to the mountain peaks. In the deposit sections of the individual large rift basins, the volcanogenic formations are not encountered. There are also no relations of effusive activity to the riftogenic faults.

The Vitim basalt field is sharply shifted to the southeast from the axis of the rift zone: the greater part of it is even located beyond its limits -- in the Transbaykal region of moderate mountain formation.

The third field of the basic effusives is located in the upper part of the Udokan ridge, that is, some shift of the area of manifestation of the Cenozoic volcanism from the axis of the rift zone in the direction of Transbaykal is noted here.

In the Neogene-Quaternary volcanic complex normal olivine basalts and andesite-basalts predominate, among which interlayers of subalkaline differences are encountered on the various levels of the section. Andesites and trachites are encountered in places among the latest eruptions in the Udokan effusive field (Solonenko, V., 1946b; ACTIVE TECTONICS..., 1966; Florensov, et al., 1968). A detailed investigation of the geological and geophysical materials with respect to the Baykal rift zone with its obviousness has demonstrated the superposed nature of its latest structure (Solonenko, V., 1968; Zorin, 1971). The southwestern flank of the zone is located in the Caledonide region, the central part is in the Baykalide region, and by its northeastern section it intrudes into the region of development of the karelides and more ancient structures of the Aldan Shield. In the northeast the rift basins intersect the axes of the ancient folds at large angles. In the southwest, although approximate correspondence of the rift fractures to the linear elements of the Baykal and Caledonian structure is observed, the rift basins themselves do not coincide with respect to their position in the plan view with the pre-Cenozoic negative structures. In the vicinity of the Selenga River delta, the Baykal Lake basin intersects at a significant angle the narrow branching of the Mesozoic trough, and the Chara basin cuts the Jurassic intermontane depression (ACTIVE TECTONICS..., 1966). Thus, the rift structural forms of the Baykal zone owe their origin only to the latest tectonic movements. Certain features of the succession of its structure from the ancient tectonic plan (such as the matching of the strikes of the structures in individual sections, use of fragments of ancient dislocations with a break in continuity) are connected with the attachment of the latest deformations to the mechanical nonuniformities of the earth's crust occurring in the pre-Cenozoic phases of development of Pribaykal'ye.

Transbaykal Region of Moderate Mountain Formation

Narrow linearly elongated basins of the Transbaykal type have developed here (Florensov, 1960). With respect to their length, they are commensurate with the large rifts, but their width usually does not exceed 15 to

20 km, and the thickness of the Cenozoic sediments in them varies from 0 to 50 meters; in rare cases it rises to 100 to 150 meters. The width of the uplifts separating them is 20 to 40 km. The relative amount that the peaks of the uplifts rise above the bottoms of the adjacent basins is 300 to 800 meters.

In addition, in Transbaykal, positive and negative structural forms of the first order are isolated, with respect to which the basins of the Transbaykal type and the uplifts separating them appear as second-order structural forms. The positive structural zones are large arched uplifts, the altitudes of which reign over the surrounding territories. Within their limits the basins of the Transbaykal type either are absent or they are encountered rarely. For the first-order arches, a centrifugal pattern of the river network is characteristic.

The largest of them is the Daurskiy isolated by N. A. Florensov (1948). The modern geomorphological and geophysical data indicate that with respect to strike, it is expedient to separate this uplift into two arches: the Daurskiy and the Olekma-Stanovoy itself (see Fig 12). In the Shilka and Argun' interfluve, the Undino-Gazimurskoye arched uplift is isolated (Zorin, Sizikov, 1965). The width of the positive structural zones reaches 120-150 km, and the length reaches 300 km or more.

The negative structural zones are broad interarch spaces, within the limits of which the basins of the Transbaykal type are predominantly developed (see Fig 12). The largest of them is the Vitimo-Selenga basin isolated by N. A. Florensov (1948). In the Zabaykal'ye [Transbaykal] it is possible to also isolate the Aginskaya, Priargunskaya and Prishilkinskaya negative zones (Zorin, 1971).

The full scale of the vertical movements in the Transbaykal region of moderate mountain formation reaches 2000 meters (the amount that the peak of the Daurskiy arch is above the bottoms of the basins of the Vitimo-Selenga zone) which is 2.5 to 4 times less than the analogous values characteristic of the Baykal rift zone. In contrast to the latter, in Transbaykal in the latest time the ascending movements have predominated. The sections of the earth's crust corresponding to the negative structural forms of the first and second order have subsided only relatively, that is, they were left in the uplift from the adjacent territories.

Judging by the fact that the Cenozoic deposits in the basins of the Transbaykal type have in the overwhelming majority of cases an age which is no more ancient than the Pliocene, it is necessary to consider that the latest movements in the Transbaykal region of moderate mountain formation began later than the Baykal rift zone. The development of the latest structural forms here is continuing at the present time (Zorin, Sizikov, 1965).

On the whole, the Transbaykal belongs to the moderately and weakly (southeastern Transbaykal) seismic regions.

Until recently it was considered that in the Transbaykal region of moderate mountain formation, the Cenozoic basaltic volcanism has appeared broadly. However, now more and more data are being accumulated indicating the lower Cretaceous stage of the shows (Logachev, 1968). The same eruptions of the basic effusives which belong indisputably to the Cenozoic, have an extremely insignificant volume. Only the above-mentioned Vitim field of basalts which stretches to the southeastern boundary of the rift zone constitutes an exception.

The latest structural formsof the Transbaykal region of moderate mountain formation reveal an inheritance from the Late Mesozoic (Upper Jurassic to Lower Cretaceous) basins and uplifts. This inheritance has the nature of more or less complete continuity of the relative direction of vertical movements which is characteristic both for the struc ural forms of the first order and the second order (Florensov, 1963, Zorin, 1971). The differences of the latest phase from the Late Mesozoic consist in somewhat lower intensity of movements and in predominant activity of the uplifts.

In the southeastern part of the Siberian platform adjacent to the Sayano-Baykal region of intensive mountain formation, a broad and gently sloping Vernelenskoye [Upper Lena] uplift is isolated which is bordered on the southeast by the Pribaykal and on the southwest by the Prisayan foothills troughs. The maximum amount that the peaks at the uplift are above the bottoms of the troughs is 1000 to 1100 meters. The thickness of the Cenozoic deposits in the greater part of the troughs is little. from a few meters in the divides to several tens of meters in the valleys of the large rivers. In the area covered by the Pribaykal trough local basins about 2 to 3 km wide are isolated in which the thickness of the Neogenic deposits reaches 250 to 300 meters (Logachev, et al., 1964).

The greater part of the territory of the foothills troughs subsided only relatively. Therefore it is possible to consider that the structural forms of the first order of the southeastern part of the Siberian platform were formed as a result of nonuniform rise of its territory. The above-mentioned local basins were created obviously as a result of overflow of the clastic material (rock salt?) in the sedimentary mantle of the platform (Zamarayev, 1967).

The latest first-order structural forms in this region reveal only certain features of the inheritance from the corresponding elements of the Mesozoic tectonics. In the Cenozoic, the Upper Lena uplift expanded sharply at the expense of the areas of the foothills troughs which were converted to comparatively narrow zones of relative subsidence.

The territory of the Siberian platform in general is in practice aseismic.

CHAPTER IV. MECHANISM OF LATEST TECTONIC MOVEMENTS

The historical reviews of the representations of the nature of tectonic processes causing the occurrence and development of the latest structure of the southern part of Eastern Siberia are presented in the monographs by N. A. Florensov (1968) and Yu. A. Zorin (1971).

In this chapter we shall limit ourselves to the discussion of only those concepts of the mechanism of formation of the latest structure which, as it appears to us, most completely take into account the modern information about the structure and state of the depths of the investigated tectonic regions.

In their primary feature, the general concept of the structure of the earth's crust and mantle in the southern part of Eastern Siberia was developed by the end of the 1960's to the beginning of the 1970's (Zorin, 1966, 1971; Artem'yev, Artyushkov, 1967; Krylov, et al., 1970). The basic principles of this concept reduce to the following. Within the limits of the Siberian platform, the earth's crust is comparatively uniform with respect to its thickness. For the Baykal rift zone, this uniformity is not characteristic: under the large basins the earth's crust has significantly less thickness than under the mountain ridges surrounding them which enter into the system of the Sayano-Baykal arch uplift. In addition, the crust under the basins has somewhat increased density as a result of the introduction of the basic and ultrabasic intrusions. Under the rift zone the upper mantle has anomalous properties: its density and propagation rate of the seismic waves are somewhat lowered. In spite of the complex structure of the earth's depths and the high level of tectonic activity, the lithosphere of the rift zone is in a situation which is close to isostatic equilibrium. This equilibrium is realized as a result of unevennesses of the Moho section and as a result of the presence of an anomalous region in the upper mantle which insures partial compensation of the Sayano-Baykal uplift as a whole and also as a result of some rise in crustal density under the large rift basins (partial compensation for the insufficiency of the masses in the volume of the basins). The observation of isostasy (isobary) does not indicate the distance of the complete mechanical equilibrium of the "crust-mantle" system. The region of the anomalous mantle can spread to the sides

as a result of the effort to minimize the gravitational energy which is not insured by one isobary. Obviously, this phenomenon is the basic cause of the tension which is established in the rift zone both with respect to seismologic data (Misharina, 1967) and with respect to geological observations (Florensov, 1969a).

The data from geothermy (Lyubimova, 1968; Lysak, 1968), magnetometry (Novoselova, 1971) and magnetotelluric probes (Gornostayev, et al., 1970) indicate that the earth's crust and the upper mantle of the Baykal rift zone are heated to a higher degree than under the Siberian platform. With respect to intensity of heating of the terrestrial depths, Transbaykal occupies an intermediate position between the two mentioned regions. These differences with respect to the thermal state of the upper mantle permit the assumption that the roof of the asthenospheric layer has the least depth under the rift zone and the greatest under the platform (Zorin, 1971).

In Transbaykal, an increase in thickness of the earth's crust under the arch uplifts of the first order is noted. These arch uplifts in the isostatic sense turn out to be weakly overcompensated: the thickness of the crust here is 1.5 to 2 km more than that which should occur for complete equilibrium (Zorin, 1971). The latter is obviously explained by the somewhat greater strength of the lithosphere in the investigated region by comparison with the rift zone where the temperature of the earth's depths is higher.

At the present time the method of deep seismic sounding has been used to obtain new data (Puzyrev, et al., 1974), on the basis of which it is possible precisely to define the thicknesses of the earth's crust in the Baykal rift zone. From the results of the spot deep seismic sounding we have selected the determinations of the depth of the Moho section by the reflected wave method which were made with orientation of the bases approximately coinciding with the strike of the latest structures. We assume that when using the transcritical reflections, these determinations contain the least distorted information about the comparatively non-latudinal (40-50 km), but sharply expressed structural forms of the Moho section. This opinion is confirmed by the results of the acoustic simulation at the Institute of the Earth's Crust of the Siberian Department of the USSR Academy of Sciences by V. R. Navdich.[1] The results of the deep seismic soundings taken in the indicated way were compared with the altitudes of the topographic relief averaged over areas of 30X30 km.[2] The correlation coefficient turned out to be equal to 0.75±0.16. The regression equation has the form

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[1] The studies were performed on solid models with observation of the quality of the velocity ratio in the crust and the mantle.

[2] Within the limits of the rift basins, the presented values of the altitudes were used which were obtained by replacement of the masses of water (in Baykal) and the sediments by masses of the crystalline earth's crust which are equal to them with respect to magnitude.

$$H = 40 + 3.4\ h$$

where H is the Moho interface, h is the height of the average wave. This equation was used to calculate the depths of the Moho section over the entire area of the rift zone, and the new diagram of its structure was compared (see Fig 13). The former values of the depths of the base of the crust (Zorin, 1971, p 127) were retained with respect to the Siberian platform and Transbaykal in the diagram, for on the whole these values agree with the deep seismic sounding data. The outlines of the regions of the anomalous mantle are shown as boundaries of the regional minimum in the Bouguer reduction.

In the schematic of the deep structure it is obvious that the earth's crust under the basins is more precisely determined by comparison with the mountain regions, as was proposed earlier by the gravimetric data. However, the consideration of the materials of the deep seismic sounding demonstrated that the earth's crust in the rift zone (both under the basins and under the ridges) is 5 to 7 km thicker than was considered previously (Zorin, 1971).

Considering the above-presented information about the deep structure and the geological data, the development of the Baykal rift zone can be represented as follows. During the Upper Cretaceous to Paleogenic interval manifested over the entire territory of Eastern Siberian, the terrestrial depths were cooled to a significant degree, and the asthenospheric layer in this region obviously was absent.[1] In the Oligocene (and possibly even in the Eocene) progressive heating of the earth's crust occurred, in connection with which the development of the asthenospheric layer began. This layer is formed obviously as a result of the partial fusion of the upper mantle similar with respect to composition to the garnet peridotite (Belousov, 1966). Under the ancient platform where the differentiation of the material went quite far, the tops of the mantle obviously were made up of dunite with the inclusion of eclogite lenses. The formation of the asthenospheric layer is possible only at great depths, where the garnet peridotite has been preserved, that is, the mantle material not subjected to differentiation as yet. Under the rift zone and under Transbaykal a similar material obviously was preserved at less depth. Therefore the roof of the asthenospheric layer in the subsequent areas can theoretically be lifted higher than under the ancient platform. In this case convective currents are possible which promote faster heat transfer from its base to

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[1] We begin with the entirely probable situation where the asthenospheric layer occurs as a result of heating of the terrestrial depths in the phases of increased tectonic activity and disappears in the planation epoch (Lyubimova, 1970; Zorin, 1972).

the roof and in the final analysis insure its displacement upward in the uniform garnet peridotite (Lyubimova, 1970).

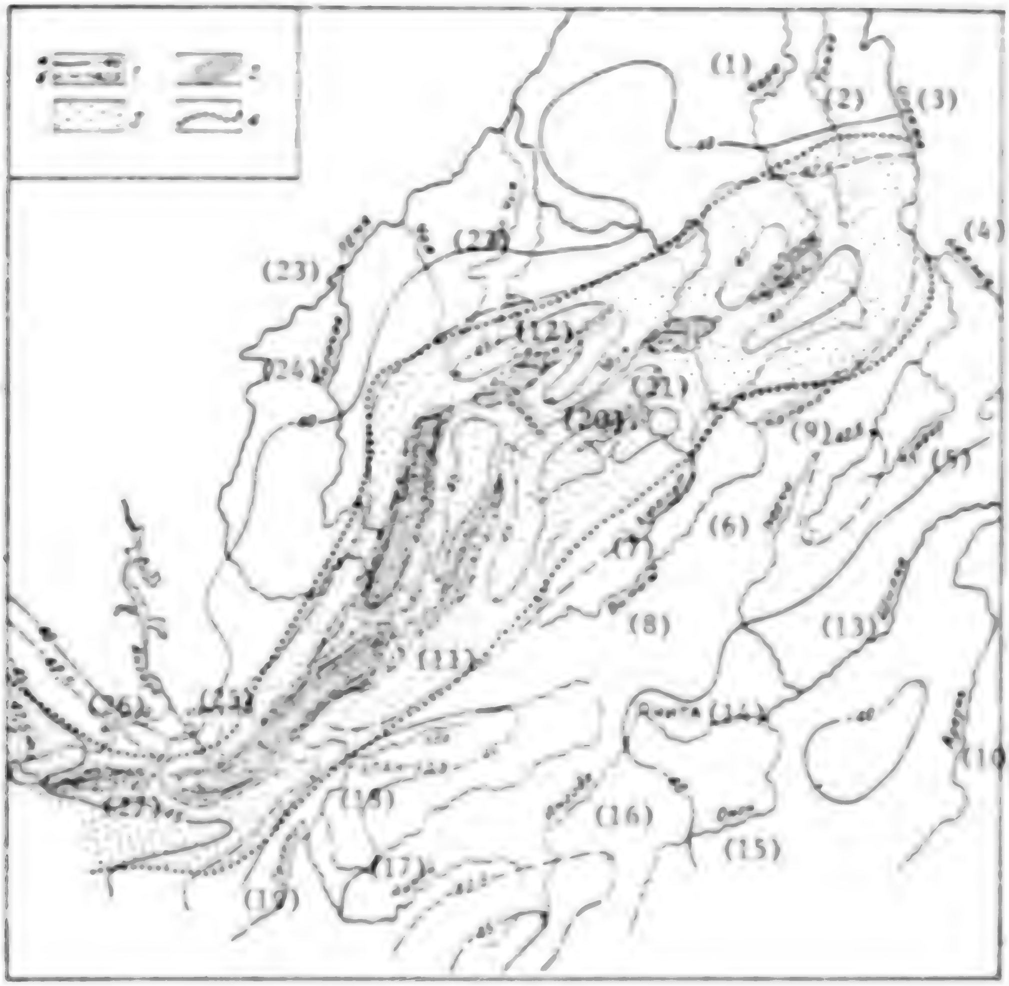

Figure 13. Schematic of the Deep Structure of Eastern Siberia. Compiled by Yu. A. Zorin

1 -- isohypses of the Moho section (numbered in km); a -- basic; b -- additional; 2 -- areas of large rift basins, under which the lower part of the crust has increased density; 3 -- area of the Baykal rift zone, within the boundaries of which the upper boundary of the region of anomalous mantle coincides with the Moho section; 4 -- boundary of the rift zone.

Key: 1. Chara; 2. Tokko; 3. Olekma; 4. Nyukzha; 5. Tungir; 6. Nercha; 7. Amalat; 8. Vitim; 9. Kalakan; 10. Argun'; 11. Barguzin; 12. Verkh. Angera [Upper Angera]; 13. Shilka; 14. Chita; 15. Onon; 16. Ingoda; 17. Chikoy; 18. Ulan-Ude; 19. Selenga; 20. Tsipa; 21. Muya; 22. Bol. Chuya; 23. Lena; 24. Kirenga; 25. Irkutsk; 26. Kitay; 27. Irkut

These arguments explain why the surface of the asthenospheric layer is at greater depth under the platform than under the mountainous regions, but the question is left open of the differences in degree of heating of the depths between the rift zone and Transbaykal. The maximum heating of the crust in the mantle of the rift zone is possibly connected with the flow of material from under the platform along the ascending surface of the asthenospheric layer.

However, another solution to the problem is more probable. Previously we proposed that the heating leading to the formation of the asthenosphere takes place as a result of conducting heat transfe. from large depths. We assumed convection only in the layer of reduced viscosity itself and explained the peculiarities of the thermal regime of the individual regions by differences in chemical composition of the upper mantle (all of the remaining positions were in the essence of the matter, consequences of this thesis).[1]

In addition, it is possible to propose, as Ye. V. Artyushkov has done (1968) that under the rift zone there is a strong additional inflow of heat. It proceeds convectively with portions of the deep heated material rising as a result of the gravitational differentiation of the nucleus and the lower mantle of the earth. On reaching the asthenosphere, this material raises the temperature and at the same time stimulates its development. The uplift of the roof of the asthenospheric layer is formed under the rift zone, and the lithosphere becomes thinner and is heated.

In the protrusion of the asthenosphere, as a result of gravitational differentiation, the relatively light material is accumulated, forming a lense of anomalous mantle. Judging by the magnitude of the limiting velocity in the Moho section, with respect to its chemical composition the anomalous mantle corresponds to a mixture of peridotite with a comparatively small part of basalt (Cook, 1962). The accumulation of this material causes an isostatic rise of the lithosphere, that is, the formation of an arch uplift (Zorin, 1971).

In the gravitational field of the earth, the lens of material having lower viscosity must spread in the direction insuring tension of the earth's crust and the formation of rift bases. The continuous inflow of such material from the depths can insure prolonged existence and development of a broad arch and rifts. Thus, we arrived at the concepts of the ascending convective current. The convection obviously has a chemical nature, that is, it is the consequence of gravitational differentiation in the material of the earth. The horizontal branch of the current, as we assumed, is located in the upper part of the asthenospheric layer.

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[1] This point of view obviously is entirely acceptable for many regions of the earth experiencing weak and moderate activity in latest time (in particular, for the Siberian platform and Transbaykal).

The large rift basins are formed as a result of thinning of the crust during tension of it. This deformation is represented as plastic, which in the upper, least heated part of the crust is complicated by shifts with respect to faults (Zorin, 1966; Artem'yev, Artyushkov, 1967). Some role in the development of the large rifts is also played by the isostatic subsidence of the crust occurring as a result of an increase in its weight as a result of introduction of the basic and ultrabasic intrusions. The space required for introduction of the intrusions is also released as a result of tension. Correspondingly, the thinning of the crust and the increase in its weight are two aspects of a unique process of destruction of the thick continental crust.

The small "generating" basins in the rift zone are formed as a result of settling of the blocks, wedging the joints opened during tension of the crust. The association of the powerful earthquakes with the "generating" basins is connected with the exceptional role of the dislocations with a break in continuity in their formation.

The height of the arch and the rates of development of the basins are determined by the speed of ascending convective flow in the mantle. In the Oligocene to Lower Pliocene, the flow rate is small, and therefore the altitude of the Sayano-Baykal arch uplift is small. The development of the basins proceeds comparatively slowly. The increase in rate of ascending flow in the Middle Pliocene has led to rapid increase in the arch, the formation of broken mountain relief and accelerated development of the rift basins. With an increase in the rates of neotectonic movements and deformation of the crust, the role of the dislocations with a break in continuity has been augmented.

Since the uplift of the asthenospheric layer under the rift zone is asymmetric, the horizontal branch of the convection flow is directed predominantly in the direction of Transbaykal. This flow could level out the steepness of the eastern slopes of the "antiroots," the asymmetry of the latter, on the basis of the isostatic tendencies, was reflected in the surface structure of the large rift basins.

The spreading of the lens of the anomalous heated material in the direction of Transbaykal probably explains the shift in this direction of the regions of manifestation of the predominantly basaltic volcanism. This material reaches the location directly under the earth's crust from great depths, weakly differentiated. For the fusion of basaltic magma from it and accumulation of significant volumes of it, a great deal of time is needed in which the differentiated material can shift significantly in the direction of Transbaykal.

The above-described concepts of the mechanism of the formation of the rift structural forms of the Baykal zone are theoretically similar to a number of the principles of the hypothesis of the "new global tectonics" (EARTH'S CRUST...., 1973). However, in our opinion, the large rift

basins of the investigated zone are formed to a significant degree as a result of elastic stretching of the heated earth's crust (the dislocations of the break in continuity are not deep and develop predominantly in the upper part of the crust), at the same time as the indicated hypothesis presupposes spreading of in practice the nondeformed plates of the lithosphere and formation of a new crust in the open slit.

The calculations indicate that for the formation of the entire Baykal rift zone a total stretching on the order of 20 to 35 km was required (Zorin, 1971), which does not compare at all with the colossal and scale horizontal shifts of the lithospheric plates which are proposed by the hypothesis of the "new global tectonics."

This hypothesis occurs as a result of the study of the ocean regions. The rifts developed there are grandiose with respect to their extent. They are much broader than the Baykal arch and the midoceanic ridges. At the present time it is not clear whether the above-mentioned differences in interpretation of the mechanism of formation of the continental and oceanic rifts are connected with another scale of manifestation of the similar deep processes or certain peculiarities of the interpretation of the geological data by the hypothesis of "new global tectonics" are explained by the fact that the structure of the ocean rifts has been studied still in very general form, schematically, with omission of important details.

The main peculiarities of the structure and the state of the depths of the Transbaykal region of moderate mountain formation are, in our opinion, the following. There is no region of dispersion of the upper mantle here. Under the first order arch uplifts, the earth's crust is thickened. Here its thickness is 1.5-2 km more than that required by the condition of complete isostatic equilibrium, that is, these uplifts are somewhat overcompensated (Zorin, 1971). The continuing rise of the arches is in accordance with the direction of forces trying to put the crust in a state of isostatic equilibrium. Since in Transbaykal in the Neogene-Quaternary period predominantly uplifts developed (negative structural forms were only left behind them in the rise), it is possible to show that the isostatic movements played a significant role in the development of the latest structure.

The inheritance of the latest structural forms from the Late Mesozoic is an important characteristic of the investigated region. The Neogene-Quaternary arch uplifts occurred at the location of the positive forms existing in the Late Jurassic to Early Cretaceous (Florensov, 1968). In addition, a close correlation was established in Transbaykal between the mean values of the modern thickness of the earth's crust in the large zones and the intensity of manifestation of the Late Mesozoic (predominantly Late Jurassic) granitoid magmatism (Zorin, 1971). As is known, the formation of the granitoid intrusion complexes is connected with the process of increased thickness of the crust and with uplift of its surface. Therefore it is possible to propose that in the age of the Late Jurassic to Early Cretaceous the areas of the latest uplifts where the Late Mesozoic

The possibility of the formation of the landslip-landslide from the transient earthquake is excluded inasmuch as in the adjacent zones with favorable conditions for the development of the gravitational process such phenomena were not noted.

With respect to genetic type it is necessary to consider the structure in the category of seismogravitational and, of course, tying the earthquake epicenter to it has a certain amount of conditionality.

The time of the formation of the structure can be determined only by the age of the trees (150 to 200 years old) along the displacer.

Strong Earthquakes with Respect to Seismostatistics

The first information on the frequent earthquakes in eastern Siberia belonged to the end of the 17th century. The seismostatic data for the 18th to the 20th centuries are more or less reliable only for Irkutsk, but they pertain only to the strong earthquakes with epicenters in Southern Pribaykal'ye and Northern Mongolia. The strong earthquakes occurring in the northern part of Baykal and along the entire eastern part of the Baykal rift zone are not felt in Irkutsk. The earthquake of 1 February 1725 which would not attract attention if it did not encompass an enormous area of eastern Siberia and did not show up very effectively in Transbaykal constituted an exception.

The extremely low and nonuniform population of the high seismic regions of Eastern Siberia (with the exception of the southern basins of the Baykal system), the absence of populated places to 1932 in the entire rift zone of Stanovoye Nagor'ye [Highlands] do not permit frequent, even approximate determination of the location of the epicenters of many of the strong and in part, obviously, disastrous earthquakes of the 18th and 19th centuries.

The description of all of the known strong earthquakes (and there are more than 650 of them) would take up a great deal of space. The analysis of the available information on the strongest earthquakes has previously been made more than once. However, this subject awaits special investigation, especially considering that the library of the Eastern Siberian Division of the Geographic Society and the archives burned during the Irkutsk fire of 1871.

All of the archives, the chronicles, newspapers, and individual publications of the 19th and the beginning of the 20th centuries must include macroseismic data on certain earthquakes for which it turned out to be possible more or less moderately to determine the epicentral regions and in individual cases, to construct the schematic maps of the isoseisms. All the information on these earthquakes was presented in accordance with the MSK-64 scale (Medvedev, et al., 1965).

Table 10

Catalog of Strong (M≥) Earthquakes in Pribaykal'ye

(a) Дата	(b) Час	(c) Координаты эпицентра		M	I_0	Примечание (f)
		(d) с. ш	(e) в. д			
1	2	3	4	5	6	7
1/II 1725	11	56,5°	118,5°	⩾8,0	11—12	Чина-Вакатская структура (см. табл. 12) (g)
27/VI 1742	5—7	Ср.-Южн. Байкал (h)		7,5	10	
24/X 1769	13	51,0—52,5	104,5—106,5*	7,0	10	
8/VIII 1771	2	51,8±0,5	105,4	5,5	8	
4/XII 1772	21	50,7	106,5	6,0	8	
1/VIII 1779	13	52,5	106,0	5,7	8	
2/IX 1814	20	51,8	102,2	5,5(?)	9	
16/XII 1814	23	51,0—51,5	104,5—106,0*	6,5	9	
7/III 1820	?	51,8	101,6	6,0(?)	9	
май (i) 1827	?	57,5	107,7	6,0	8	Эпицентр вблизи (j) окружности радиусом 60 км. См. Сейсмотектоника..., 1968
8/III 1829	21	51,7	101,3	7,0	9	
19/III 1829	?	51,4	104,5	7,0	9	См. Сейсмотектоника..., 1968 (k)
12/IV 1832	0	49,5	107,4	6,0	8	Эпицентр вблизи окружности радиусом 215 км (l)
14/VI 1835	13	50,1	106,7	5,5	8	То же, радиусом 90 км (m)
18/VIII 1839	1	51,7—52,5	105,7*	5,8	8	» »
17/VIII 1846	23	51,5—52,5	106,0*	6,5	9	» »
11/IV 1856	21	51,5	106,5	5,5(6,0)	8	
25/XII 1856	22	51,0—52,5	104,5—106,5*	5,0	7	
27/XII 1856	8	51,5	105,5	5,0	7	
22/VI 1861	23	51,0	106,9	5,5—6,0	8	То же, радиусом 75 км (n)
12/I 1862	9	52,5	106,8	6,7	9	Цаганское (o)
13/I 1862	7	52,3	106,7	7,1	10	Образовался зал. Провал (203 км²) (p)
27/VII 1862	17	49,5	106,5	5,5	8	
21/V 1865	20	52,0	106,0	5,5	8	
8/III 1866	4	51,7	104—105*	6,0	8	
3/II 1869	21	51,0—52,5	104,5—106,5	5,0*	7	
1/XI 1869	15	53,5	109,0	5,0	7	
19/VI 1870	7	51,7	104,5	5,5	8	
3/III 1871	23	52,0	106,0	6,5	9	
6/VII 1874	14	51,0—52,5	104,5—106,5*	5,5	8	
31/V 1876	17	51,0—52,5	104,5—106,5*	5,5	8	
31/VIII 1876	15	51,0—52,5	104,5—106,5*	5,5	8	
23/I 1881	22	51,0—52,5	104,5—106,5*	5,5	8	
10/II 1881	1	51,0—52,5	104,5—106,5*	5,5	8	
9/X 1883	4	51,5—52,5	104,5—106,0*	5,5	8	
12/I 1885	16	52,5	106,5	6,5	9	
16/XI 1885	?	52,0	107,5	5,0	7	
19/XI 1885	20	51,3	108,1	6,5	9	
23/III 1902	9	51,8	105,9	5,1	7	

[See key on p 192]

[Table 10, continued, see key on p 192]

(a) [1]		(b) [2]	(d) [3]	(e) [4]	5	6	(f) [7]
11/IV	1902	23	51,5	104,5	6,4	9	
17/VIII	1902	18	56,6	112,8	6,7	9	Чурокаиское (q)
8/IX	1902	21	52,7	107,3	5,0	7	
26/XI	1903	11	52,7	107,6	6,7	9	
27/VI	1904	21	52,5	106,5	5,3	7	
28/IX	1904	9	51,6	105,2	5,1	7	
9/VII	1905	9	49,5	97,0	8,4	11	
23/VII	1905	2	49,2	96,0	8,7	12	
8/II	1906	9	52,5	107,5	5,0	7	
9/V	1907	22	52,2	106,5	5,8	8	
17/II	1912	13	51,8	105,7	5,4	7	
22/V	1912	8	51,7	103,8	5,5	7—8	
15/VI	1912	7	51,9	105,8	5,3	7	
20/V	1913	9	52,5	106,5	5,5	8	
21/XII	1913	2	50,0	104,4	5,0	7	
10/I	1915	0	49,6	99,7	5,8	8	
25/IX	1915	20	50,5	105,0	5,5	8	
29/IV	1917	11	56,0	113,8	6,7	9	Северобайкальское (r)
9/XI	1924	1	52,0	103,0	5,2	7	
7/II	1925	17	48,0	105,0	5,4	7	
24/III	1926	11	50,0	97,0	5,5	8	
11/II	1927	10	56,0	115,0	5,2	7	
18/XII	1928	9	52,0	101,6	5,0	7	
10/V	1929	11	50,2	106,3	5,6	8	
6/V	1931	17	52,5	108,0	5,0	7	
6/VIII	1931	18	55,3	109,4	5,9?	8?	Опустилась дельта р. Верх. Ангары (s)
19/VIII	1932	17	48,7	96,5	5,0	7	
26/IV	1934	13	52,1	105,7	5,2	7	
15/X	1934	18	51,3	109,5	6,0	8	
2/III	1935	3	51,5	107,0	5,3	7	
18/V	1935	18	51,5	105,0	5,0	7	
11/III	1936	8	56,5	112,5	5,1	7	
27/V	1936	14	51,5	105,0	5,5	7	
25/XII	1937	9	55,6	111,7	6,1	8	
24/II	1939	20	49,7	97,3	5,0	7	
10/III	1939	7	48,3	97,8	5,5	8	
19/V	1939	18	52,2	98,8	5,9	8	
26/V	1939	9	53,9	108,8	6,1	8	
4/VI	1939	7	53,0	107,5	5,0	7	
23/IX	1940	10	56,1	112,1	5,7	8	
1/VII	1941	6	52,6	106,8	5,6	8	
10/IV	1949	12	51,6	104,6	5,0	7	
6/V	1949	14	53,7	109,7	5,8	8	
4/IV	1950	18	51,8	101,0	7,0	9	Мондинское (t)
8/IX	1950	14	51,7	100,9	5,0	7	
17/IV	1952	9	52,6	97,0	5,2	7	
25/XI	1952	13	52,7	106,8	5,0	7	
3/II	1953	8	51,4	100,7	5,0	7	
19/VI	1953	5	57,0	114,7	5,1	7	
7/V	1954	0	49,0	103,0	5,0	7	
5/X	1954	11	54,5	109,0	5,3	7	
[illegible]/II	1957	20	50,0	105,5	6,5	9	

[Table 10, continued, see key on p 192]

(a) 1	(b) 2	(d) 3	(e) 4	5	6	(f) 7
27/VI 1957	0	56,1	116,4	7,9	10—11	Муйское (u)
29/VI 1957	22	56,4	116,9	6	8	
20/VIII 1957	22	50,5	96,5	5,0	7	
31/VIII 1957	12	48,8	100,0	5,7	8	
3/I 1958	22	56,0	114,0	5,6	8	
5/I 1958	11	56,6	121,1	6,5	9	Нюжинское (v)
24/I 1958	4	56,4	116,2	5,8	8	
10/IV 1958	10	52,0	100,0	5,8	8	
23/VI 1958	5	48,7	102,9	6,2		
10/VIII 1958	11	51,7	102,0	4	5—6	
14/IX 1958	14	56,7	121,0	6,5	9	Олекминское (w)
2/XI 1958	0	57,0	121,0	5,0	7	
29/VIII 1959	17	52,7	107,0	6,8	9	Среднебайкальское (x)
8/X 1959	14	52,7	107,1	5,1	7	
26/IV 1960	6	56,5	120,5	5,0	7	
18/VII 1960	4	55,6	110,4	5,1	7	
6/X 1960	16	52,7	108,1	5,5	8	
25/VI 1961	19	52,4	106,7	5,2	7	
25/VI 1961	19	52,4	106,7	5,2	7	
27/VII 1961	23	54,1	110,0	5,0	7	
28/X 1961	22	53,6	108,8	5,5	7	
22/I 1962	7	52,4	100,2	5,5	7	
13/VIII 1962	20	53,6	108,7	5,2	7	
11/XI 1962	11	55,9	113,1	6,0	8	Муяканское (y)
10/II 1963	6	52,6	106,9	5,0	7	
22/VI 1963	20	53,1	121,2	5,2	7	
1/XII 1963	4	55,9	112,0	5,0	7	
21/XI 1965	3	50,5	112,0	5,3	7	
10/V 1966	21	51,9	98,9	5,8	8	
30/VIII 1966	6	51,7	104,6	5,5	7	
31/XII 1966	0	55,7	110,8	5,0	7	
5/I 1967	0	48,0	103,0	7,8	10	Моготское (z)
15/I 1967	19	55,6	110,8	5,2	7	
18/I 1967	5	56,6	121,0	7,0	9	Тас-Юряхское (aa)
20/I 1967	1	48,0	103,0	7,0	9—10	
11/II 1967	9	52,1	106,5	5,2	6	
7/VI 1967	7	49,6	97,1	5,0	7	
22/VIII 1967	23	56,2	112,9	5,5	7	
21/VII 1968	1	55,2	113,4	5,1	7	
31/VIII 1968	18	56,4	115,8	5,5	8	
26/XI 1968	18	55,9	111,5	5,3	7	
28/III 1970	9	52,2	105,9	5,5	7	
15/V 1970	20	56,8	117,7	5,6	7—8	
18/XII 1971	22	56,2	114,2	5,0	7	
26/II 1972	23	50,6	96,9	5,7	8	
9/VIII 1972	19	52,8	107,7	5,2	7	
16/VI 1973	12	54,8	112,6	5,0	7	
21/VI 1974	20	56,3	117,7	5,3	7	
8/X 1974	3	60,6	118,5	5,2	6—7	
29/XI 1974	21	51,8	98,5	5,4	7	
18/XII 1974	7	48,4	103,2	5,6	8	
6/II 1975	21	56,4	117,9	5,2	7	

(bb) Примечания. 1. Каталог дан по С. И. Голенецкому (с некоторыми изменениями). Эпицентры и магнитуды ряда землетрясений, зарегистрированных инструментально, переопределены на ЭВМ по программам, составленным в ИЗК СО АН СССР и ИФЗ АН СССР. Даты всех землетрясений по новому стилю и Гринвичскому времени. 2. Звездочкой отмечены землетрясения с эпицентром в полосе между пунктами, ограниченными указанными координатами.

[Key to Table 10, pp 189-191]:

a. Date
b. Hour
c. Coordinates of the epicenter
d. north latitude
e. east longitude
f. Note
g. China-Vakatskaya structure (see Table 12)
h. Central to Southern Baykal
i. May
j. Epicenter near circular with a radius of 60 km. See SEYSMOTEKTONIKA [Seismotectonics]..., 1968
k. See SEYSMOTEKTONIKA..., 1968
l. Epicenter near a circle 215 km radius
m. The same, 90 km radius
n. The same, 75 km radius
o. Tsaganskoye
p. Proval Bay was formed (203 km^2)
q. Churokanskoye
r. Severobaykal'skoye [Northern Baykal]
s. The Verkh. Angara [Upper Angara] River delta subsided
t. Mondinskoye
u. Muyskoye [Muya]
v. Nyukzhinskoye [Nyukzha]
w. Olekminskoye [Olekma]
x. Srednebaykal'skoye [Central Baykal]
y. Muyakanskoye
z. Mogotskoye
aa. Tas-Yuryakhskoye

bb. Notes. 1. Catalog presented according to S. I. Golenetskiy (with some alterations). The epicenters and magnitudes of a number of earthquakes recorded instrumentally are redetermined on the computer by the programs written at the IZK Institute of the Siberian Department of the USSR Academy of Sciences and the Institute of Earth Physics of the USSR Academy of Sciences. The dates of all of the earthquakes are given in new style [Gregorian calendar] and Greenwich time. 2. The asterisk denotes earthquakes with the epicenter in the strip between the points bounded by the indicated coordinates.

The procedure for determining the epicenters of historical earthquakes consisted in the following:

1. The epicenter was located inside the area outlined by the isoseism of maximum force or inside the triangle with peak force. Here it was placed at an equal distance from the points experiencing the greatest tremor.

2. In the case of one-way (with respect to strike of the Baykal seismic belt) location of the force, the generalized radii of the isoseisms of the known earthquakes were used. Here, the shortest distance to the first seismically active fault in which the earthquake epicenter was proposed was taken.

3. The intensity of the earthquake in the epicenter was determined not only by the macroseismic data, but also by the dimensions of the areas encompassed by the tremor by comparison with the maps of the isoseisms of modern earthquakes. It was considered to be a minimum of one force point greater than at the two places with maximum force located on a straight line in different directions from the proposed epicenter.

4. If only two places with identical force were known, located on the ends of the line cutting the morphostructures of the investigated territory, then the epicenter was placed on the seismically active fault closest to the center of this line.

5. The epicenter was located near the area with maximum shaking where the noise reached the greatest force.

The list (see Table 10) and the map (Fig 60) cannot pretend to completeness. They do not contain certain even very strong earthquakes inasmuch as the available spotty information about them does not permit even an approximate decision to be made regarding the location of their epicenters.

It is necessary to include in these earthquakes, for example, the earthquakes in June to July in the year of 1700 and 27 June 1742, which occurred in Irkutsk obviously as force-8 with probable epicenters in Southern Baykal or the Tunka basin, the earthquakes of 1827 and 1856 felt in Kirensk, and so on. The information about many strong earthquakes in past centuries has not been preserved or found or does not offer the possibility of determining their epicentral regions and, consequently, intensity.

The list and the map include the strongest earthquake of 17 March 1783. It encompassed the territory of several millions of square kilometers -- from Lake Baykal to Kolyvanskiy Altay. Although the information about this earthquake is contradictory (Mushketov, Orlov, 1892), it can be assumed that its epicenter was located in Western Mongolia or Eastern Tuva (it was not strong in Irkutsk, and it was not felt in Transbaykal).

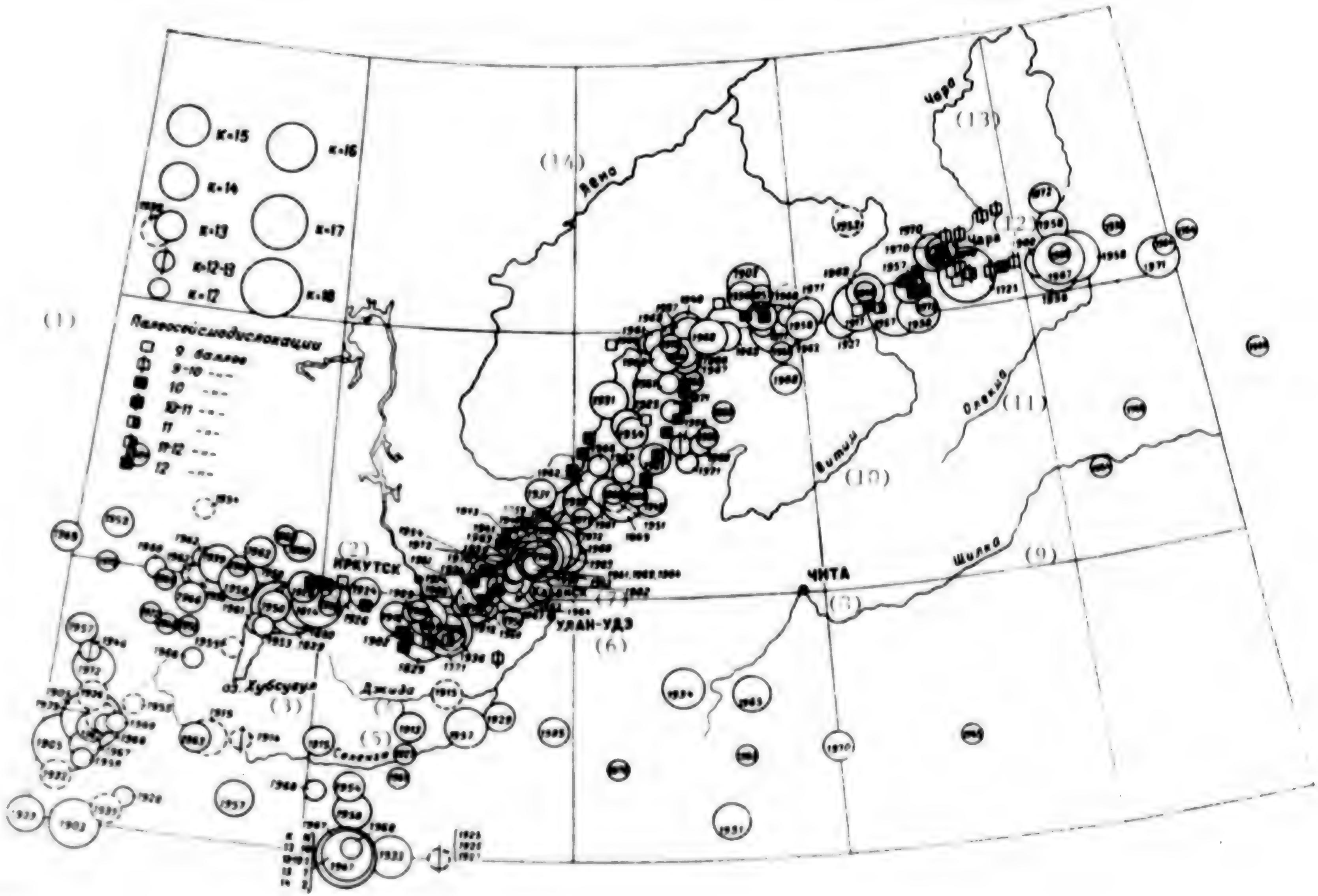

Figure 60. Map of the epicenters of the Pribaykal'ye Earthquakes (K≥12, M>4).
[See key on p 195]

[Key to map, p 194]

1. Paleoseismic dislocations
2. Irkutsk
3. Khubsugul Lake
4. Dzhida
5. Selenga
6. Ulan-Ude
7. Kabansk
8. Chita
9. Shilka
10. Vitits
11. Olektsa
12. Chara
13. Chara River
14. Lena

Judging by the encompassed area, by analogy with the known earthquakes, its intensity exceeded 10.

Some data are presented below on the appearance of individual, strongest earthquakes. The number of the earthquake in the description corresponds to the number in the list. For the remaining shocks in the table the corresponding bibliographic references are given.

Earthquake of 1 February 19725. In analyzing the information (very meager) on this earthquake and the modern data on the seismicity of Eastern Siberia, Mongolia and China, V. P. Solonenko (ACTIVE TECTONICS..., 1966, p 147) arrived at the conclusion that this earthquake was an outstanding seismic event in Siberia. It encompassed an enormous territory from Nerchinsk to Irkutsk. From Chita to Selenga (no less than 500 km) signs of force 7 to force 8 macroseismic effects were noted: cracking and hummocking of the earthen dikes on the bodies of water, deformation of the buildings in Chita. Just as during other very strong earthquakes, the trembling was nonuniformly distributed. For example, in the vicinity of Chita, the earthquake was not felt on one of the islands in the Ingoda River valley.

The epicenter could be located only in the Stanovoye Nagor'ye. If it was located in Man'chzhuriya where volcanic activity was observed at that time, the earthquake would have encompassed an enormous territory of China and could not have missed being entering in the catalogs of Chinese earthquakes.

In Southern Transbaykal and in the eastern part of Mongolia, from where the earthquake could have spread to the south of Transbaykal, there were no seismicgeological prerequisites for the occurrence of such a strong earthquake (Solonenko, V., 1959). Therefore the only highly active seismic zone with which the earthquake of 1 February 1725 could be connected turns out to be the rift system of the Stanovoye Highland. The area encompassed by the shaking was at least twice the shaking area during the Muya earthquake (M=7.9, I_0=force 10-11).

Figure 61. Section of the China-Vakatskiy fault on the left slope of the Nizhniy Ingamakit River canyon

Of the two possible seismogenic structures which could be connected with the earthquake of 1 February 1725 -- the China-Vakatskaya and Dovachanskaya -- the first is the most probable both with respect to its scale and freshness of forms (Fig 61, 62). With respect to the parameters of the seismic dislocations (see Table 9), the magnitude of the earthquake could exceed 8, and the intensity could exceed force 11-12 (ACTIVE TECTONICS..., 1966).

Earthquake of 8-19 March 1829. From 24 February to 3 April 1829, one earthquake followed another in Pribaykal'ye and Transbaykal. From 8 to 19 March they were felt daily three or four times a day.

The earthquakes encompassed the Nizhneudinskiy, Irkutsk, the Verkhneudinskiy, the Nerchinskiy districts and Northern Mongolia. "These earthquakes are mentioned in the literature as one earthquake occurring on 8 March (24 February) 1829. In reality obviously there were two earthquakes: 8 March (24 February) with the epicenter in the vicinity of the Turanskaya basin and 20 (19 Greenwich) March (8 March) with the epicenter in the southern part of Baykal" (SEISMOTECTONICS..., 1968, p 60). The first earthquake was destructive in the Tunkinskiy region; in the Turanskiy border guard station there were "terrible shocks accompanied by a roar," the wooden barn was destroyed, and in Shimkiy the stoves shook and several of the chimneys fell (Mushketov, Orlov, 1892).

The force of the second earthquake was moderate in Tunka, but very significant in Irkutsk (to force 8) and Kyakhta (force 7-8). In Irkutsk many buildings were damaged or destroyed, and cracks formed in the ground. "Considering that the earthquake was somewhat stronger in Irkutsk than in Kyakhta (100 and 200 km from Southern Baykal respectively) and significantly weaker in Verkhneudinsk (Ulan-Ude) and the Tunkinskaya [Tunka] basin, it is possible to propose the location of its epicenter on the Baykal slope of Khamar-Daban, where traces of the epicentral zones of recent, but unknown earthquakes have been detected" (Solonenko, 1964a, p 170).

Unfortunately the information about these earthquakes is meager and contradictory. The dates coincide suspiciously: 24 February old style[1] -- 8 March new style[2]; 20 March new style -- 8 March old style. The notes in the Russian chronicles have served as primary sources of information extracted from foreign publications; therefore the confusion between the Gregorian and Julian calendars is entirely probable.

The Tsaganskoye earthquake of 12 January 1862 deserves special attention with respect to force and geological-geomorphological consequences. The results of examining the earthquake have been published and analyzed many times (SEISMOTECTONICS.... 1968).

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[1]Julian calendar

[2]Gregorian calendar.

Its epicenter is associated with the tectonic block bounded by the "active" faults, the subsidence of which exceeded 300 meters in the Quaternary period. On the lake side along the previous bar (the Naletovskaya Karga) there is a line of subaqual thermal and gas springs.

Figure 62. Fragment of the China-Vakatskaya seismogenic structure. Photograph by V. P. Solonenko.

The earthquake began with a slight tremor on the evening of 10 January 1862. On the next day came the first srong shock which even in Irkutsk caused significance destruction (to force 7). During the day eight earthquakes were noted in Irkutsk.

The main shock of the earthquake occurred at 1418 hours on 12 January. In the villages located on the terrace above the Tsaganskaya steppe and in the Tsaganskaya steppe, the "wooden headworks flew out of the wells like corks, the water followed them to a height of 3 sazhen'[1]" (IRGO Report, 1864).

The block of the earth's crust from the Kharauz stream to the Enkhaluk River 36 km long (according to Fitingof, 40 verst[2]), and 20 km wide subsided after 7-8 meters. On the southeast this block was bounded by a clearly expressed fault with a vertical amplitude to 8 meters. The trench next to the fault was up to 4 meters wide and 6 meters deep.

[1] 1 sazhen'=2.13 meters.

[2] 1 verst=1066.8 meters.

It was traced from the shore of the Baykal through the Oymur vill e to Kudary village, that is, almost to the central part of the Selenga River delta. The Tsaganskaya steppe about 20 km long and 9-14 km wide subsided beneath the level of Baykal and the Proval Bay was formed. According to the map compiled by Colonel Ryabov in 1862, the area of Proval Bay was 203 km^2 (Fig 63).

The Bar (Karga) which borders the Tsaganskaya steppe on the lake side prevented free access of the Baykal water to the Tsaganskaya steppe, although during the earthquake water with broken ice splashed across the Naletovskaya Karga to a height of 3.5-4 meters and reached more than 2 km onto the Tsaganskaya steppe. On 13 January the bar was broken in three locations, and the Baykal water poured through the breaks.

In Irkutsk, the main phase of the earthquake continued for 1-1/2 minutes. At the same time, cracks formed in all of the stone buildings, sometimes, gaping holes and many churches were damaged. The earthquake was accompanied by loud noise, cracking of the earth and ice on the ri s. Continuous vibration of the earth was felt for 32 minutes.

The strip of most powerful earthquakes (to force 8) from Proval passed to the southwest through Kabansk, to Selenginsk and Zagustayskaya steppe. Posol'sk, Verkhneudinsk (Ulan-Ude) and Barguzin remained outside the Pleistoseist region.

During the second half of the day and night, the earthquake was felt in Irkutsk on the average every 7 to 10 minutes and in Selenginsk every 2 to 3 minutes. Gradually abating, the aftershocks continued for 16 months especially frequently and strongly in January and February of 1862.

The earthquake encompassed an enormous area -- on the order of 2 million km^2. Colonel Taskin, who participated in studying the earthquake, pointed out that the "destruction of buildings is observed for approximately 600 versts from Kudara" (IRGO Report, 1864). Large rock avalanches were recorded up to 400 km from the epicenter.

The intensity of the Tsaganskiy earthquake is estimated differently, sometimes even in the same papers. In the "Atlas..." (1962) force 10 on the map, and in the earthquakes list force 9. A. V. Voznesenskiy (1932), who had the possibility of making broad use of the materials from the first documentation, considered that the earthquake reached force 11. Obviously, the comparative estimate of the Tsaganskiy earthquake with modern, well-studied earthquakes, is most indicative.

In the case of the Central Baykal earthquake (M=6-3/4, I_0=force 9) with near center zone, the force 8 effects extended a distance of up to 25-30 km from the epicenter; during the Tsaganskiy earthquake, 170-180 km, and the areas of perceptible quaking were 0.8 and 2 million km^2 respectively. It is clear that with respect to the intensity the Tsaganskoye earthquake sharply exceeds the Srednebaykal'skoye, and with

respect to its parameters approaches the Muya earthquake ($m=7.9$, I_0=force 10-11, and the area of the perceptible quaking is no less than 2 million km^2).

Along the length of the main fault (20 km), the minimum magnitude of the earthquake was 7.4 (see Chapter I).

Thus, the entire complex of signs indicates that the intensity of the Tsaganskiy earthquake was no less than force 10.

The earthquake of 12 January 1885 was felt in the southern part of Eastern Siberia with an intensity from force 3 to 6 (Table 11).

By the time it is possible to consider that two earthquakes occurred that day: between 1000 and 1100 hours and at 1142 to 1150 hours. However, the low precision of the time service during those years and, the main thing, absence of information from certain stations about two shocks force us to assume that actually one earthquake occurred with an intensity of no less than force 8 inasmuch as the stations with force 3 and force 4 quaking were up to a distance of 675 km from each other (Tulun and Tarbagatay villages).

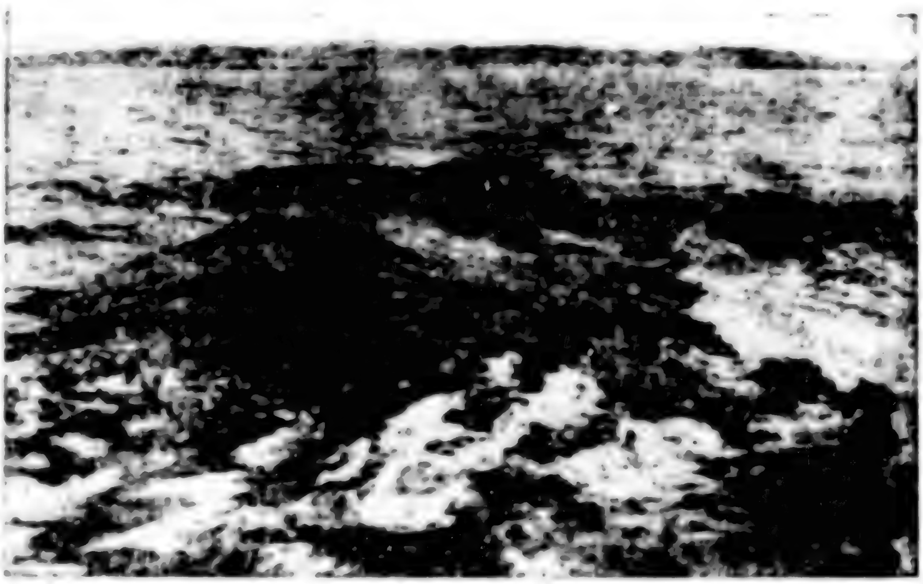


Figure 63. Proval Bay occurring during the earthquake of 11 to 12 January 1862. Photograph by V. P. Solonenko.

Table 11

Macroseismic Information about the Earthquake of 12 January 1885 (Mushketov, Orlov, 1892)

Item No	Populated place	Time of earthquake (hrs, min)	Force	Epicentral distance, km	Note
1	Irkutsk	10-40	6	150	Boom similar to claps of thunder
2	Kyakhta	10-30	3	250	
3	Balagansk	11-00	5	250	
4	Tulun	11-00	3-4	450	
5	Tarbagatay	11-00	3	230	
6	Selenginsk	11-42	5	160	Noise similar to striking a copper bell
7	Kabansk	11-45	5	50	
8	Barguzin	11-45	3-4	250	
9	Verkholensk	11-45	4	180	Roar
10	Kachug	11-45	4	170	
11	Biryul'ka	11-45	5	145	

The Churokanskoye Earthquake of 18(17) August 1902. On the Verkhneangarskiy [Upper Angara] ridge in the headwaters of the Churokan River, the right tributary of the Churo River (the basin of the Upper Angara River), the participants in the Baykal hydrographic expedition of F. K. Drizhenko noted "four shocks of the strong earthquake at 2 o'clock in the morning local time. The first weak and second significantly stronger and the last two weak again. An enormous avalanche occurred during the second shock on the mountain on the opposite bank of the river. A stone avalanche took out the forest on the right bank of the river. Everyone not only woke up but were thrown out of their beds." According to these data, the the earthquake intensity at the observation point could be estimated at approximately no less than force 7-8. It is possible that the same earthquake was felt with force 4-5 at the Bodayba mines, where many of the people woke up and noted the swaying of hanging objects and clanking of dishes. At the Irkutsk magneto-meteorological observatory, no recordings were noted on the Mil'na and Bosha pendulums.

The search for the epicentral zone in 1965 did not lead to a unique solution of the problem. Two seismogenic structures were discovered which could have conditionally been connected with the 1902 earthquake. One of them was the Ogney structure located on the right bank of the river by the same name (the Upper Angara ridge where rejuvenation of a section of one of the feathered upland faults of the Verkhneangarskiy [Upper Angara] fault occurred).

The second -- the Yanchukanskaya structure -- is located on the south side of the Verkhneangarskaya [Upper Angara] basin on the sloping foothill plain of the Northern Muya [Severo-Muyskiy] ridge between the Yanchuy and the Yanchukan Rivers. In the first case the earthquake intensity was force 9, and in the second case, 9-10. The Ogney epicenter is more probable (the F. K. Drizhenko expedition had its camp at 50 to 60 km northeast of the Ogney structure, and the earthquake intensity at the camp could have reached force 7-8).

The Baykal Earthquake of 26 November 1903 is among the strongest earthquakes of Eastern Siberia. A. V. Voznesenskiy, who first compiled the isoseism map of this earthquake considered that its epicenter was located on the Selenga River delta and had coordinates of 52.14° north latitude and 106.50° east longitude.

The analysis of the additional macroseismic material performed by V. P. Solonenko (1964a) demonstrated the impossibility of constructing an ordinary isoseismal map. In reality, within the limits of the territories subjected to the effects of the earthquake (an area of about 600,000 km^2), the intensity of the quaking noise distributed highly nonuniformly. The largest area with tremor intensity of no less than force 6 encompassed the Selenga River valley to Ulan-Ude, the east shore of Baykal to the Svyato Nos Peninsula and the valley of the lower course of the Barguzin River. With respect to size of the territory encompassed by the tremors, the earthquake of 26 November 1903 compared with the force 9 Central Baykal earthquake. Comparing the maps of these earthquakes, it is possible to propose that the intensity of the Baykal earthquake at the epicenter could reach force 9 (M=6.5), and the epicenter obviously was located somewhat northeast of the epicenter of the Central Baykal earthquake of 29 August 1959 (Solonenko, 1964).

The Tannu-Ol'skiy Earthquakes of 1905 with epicenters in Western Mongolia had intensities of force 11 and 12 and, in addition to Mongolia, encompassed significant areas in Western and Eastern Siberia.

We processed the correspondence of A. V. Voznesenskiy on these earthquakes using the MSK-64 scale. We constructed the isoseism maps, determined the areas of the earthquake-affected territories and the epicentral distances to several points (Table 12).

Earthquake of 9 July 1905, force 11, M=8.4 (Richter, 1963). In the epicentral zone of the earthquake, the fault was uncovered with the formation of a complex slip-strike thrust fault system of seismic dislocations extending up to 130 km with an amplitude of vertical displacement to 1 m.

In the territory of Russia, the earthquake was felt most sharply on the Krutobaykal'skaya Railroad and in the village of Kabansk. In the section between the Kultuk and Baykal stations (500 km from the epicenter) within the limits of the two tunnels, a shift of the rocky massif

occurred along the faults, which led to destruction of several rails in each of the tunnels.

The Earthquake of 23 July 1905, force 12, M=8.7 (Richter, 1963). The left strike-slip thrust faults were formed 370 and 90 km long with an amplitude of vertical displacement to 3.5 m and horizontal displacement to 2.4 m.

In the territory of Russia it was felt from Tomsk to Sretensk (more than 2100 km) and to Kirensk in the north (1100 km from the epicenter). The total earthquake affected area was no less than 4 million km^2 (see Table 15).

Table 12

Macroseismic Effect During the Tannu-Ol'skiy (Khangayskiy) Earthquakes of 1905

Populated place	9 July		23 July	
	Force	Epicentral distance, mm [Sic]	Force	Epicentral distance, km
Tunka	3-4	420	6-7	465
Irkutsk	5-6	550	6-7	585
Bratsk	5	765	4-5	810
Ingoda	4	1120	6	1155

The earthquake of 23 July 1905 reached maximum intensity (force 6-7) in the territory of Russia in Irkutsk, Kultuk, Tunka, Kyakhta, and Tibel'ti. Here the people could hardly stand on their feet, and many fell down. There was panic, and bells rang. The houses trembled and heavy objects fell. In many places the plaster fell of the walls, and in some the windows were broken. New cracks (up to 1.3 cm wide) appeared in the stone buildings in Irkutsk and the old ones almost doubled in size. In some buildings the cracks split the walls from the foundation to the roof. In a swamp in the vicinity of Irkutsk, spouting of groundwater was observed. The walls of the temple and the school buildings cracked in Kyakhta.

Northern Baykal Earthquake of 29 April 1917 (ACTIVE TECTONICS..., 1966). According to the meager macroseismic data (Popov, 1939) it can be concluded that the radius of the force 4 isoseism exceeded 400 km, and the area of perceptible breaks obviously amounted to significantly more than 500,000 km^2. The most remote populated places from which information was received were the village of Vorontsovka on the lower course of the Vitim River (force 4) and the settlement of Barguzin (force 4-5).

In addition, the earthquake was felt at the Bodayba mines in the city of Bodaybo with force 4-5.

The earthquake was recorded by the majority of seismic stations of the world in operation in 1917. Then the British seismological committee determined the coordinates of the epicenter (56° north latitude, 115° east longitude), and later B. Gutenberg and C. Richter (Gutenberg, Richter, 1954) determined its magnitude of $M=6\text{-}1/2$. Similar parameters were determined for the earthquake by S. L. Solov'yev: 56° north latitude, 115.5° east longitude, $M=6\text{-}1/4 \pm 1/4$.

The mechanism of the center (Vvedenskaya, 1961) agrees best with the seismogeological situation in the vicinity of the articulation of the Southern Muya ridge and the Muya basin. In 1963 a search was made for the epicentral zone. At 56.17° north latitude and 115.52° east longitude, that is, in direct proximity to the epicenter location determined by S. L. Solov'yev, the Usmun seismodislocation was established (see Table 12), the relation of which to the earthquake of 1917 is highly probable.

With respect to magnitude and scale of the dislocations, the intensity of the earthquake was force 9.

The Chikoyskoye Earthquake of 15 October 1934 occurred in the vicinity of the Yamarovka health resort. The epicentral zone was coordinated with the moving tectonic suture between the Chikoyskaya basin and the Malkhanskiy arch-block uplift -- a fragment of the Chikoyskiy deep fault. The signs of differentiated Holocene movements were clearly expressed in its zone.

According to the eyewitnesses, in the Chikoy River valley at the time of the earthquake movement of the earth waves was observed which rocked the trees sharply. The intensity of the earthquake, depending on the distance to the epicenter, reached (Popov, 1939; Solonenko, V., 1968b) force 7 at Khilok station (70-80 km); in the city of Petrovsk-Zabaykal'skiy (130-140 km) had reached force 6 (strong vibrations lasting 25-30 seconds; the windows broke in their frames; several stoves were damaged); in the cities of Ulan-Ude (230-240 km), Kyakhta (280-290 km) and Slyudyanka (300-310 km), force 5; in the villages of Kabansk (300-310 km), Ust'-Barguzin (320-330 km), Babushkin (340-350 km), Torey (400-410 km), force 4. Judging by the magnitude $M \sim 6$) and noted effects of the earthquake at the indicated distances, the intensity of the earthquake in the epicenter could not be less than force 8.

Mondinskoye [Mondy] Earthquake of 5 April 1950. The main phase of the earthquake ($M=6\text{-}3/4$, I_0=force 9) had the nature of a double shock.

The surface effects in the epicentral region encompassed the western part of the Mondy basin. Here, on the high (6th to 9th) terraces of the left bank of the Irkut River in the vicinity of the Tunka fault, a system of echelon type fault joints of northwestern and sublatitudinal orientation arose with a total extent to 2-2.5 km (see Figure 64). Part of the

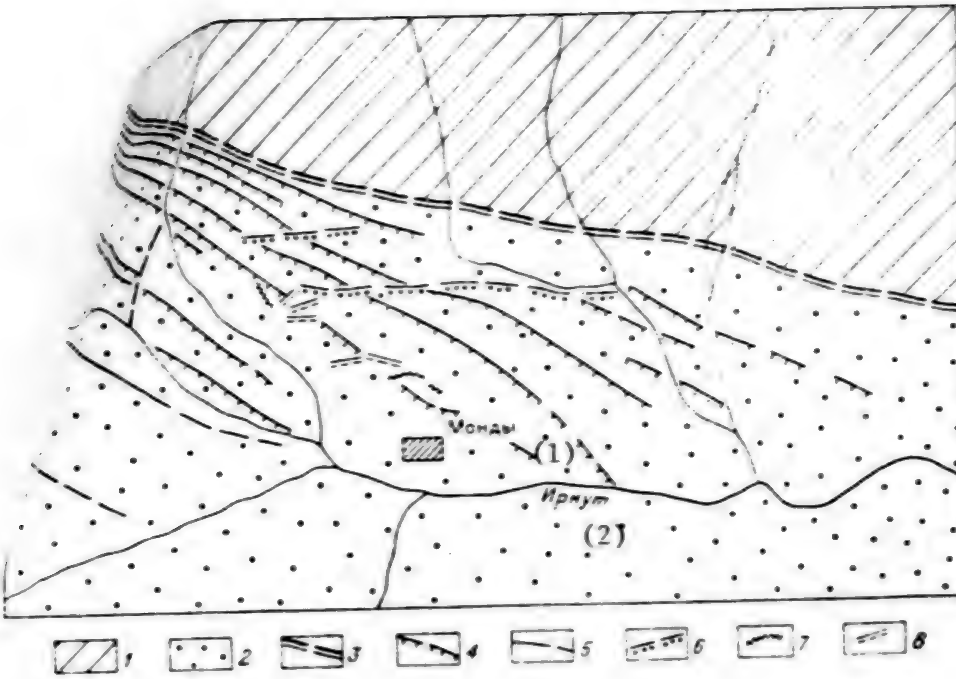


Figure 64. Structural-tectonic schematic of the epicentral part of the Mondinskiy force 9 earthquake of 4 April 1950. Compiled by V. M. Zhilkin (using the data of M. Ye. Medvedev).
1 -- region of subversion of the pre-Cenozoic foundation covered by the unbroken sedimentary complex; 2 -- region of its uplift; 3 -- Tunkinskiy longitudinal fault; 4 -- fault scarps of the Mondinskiy terraces; 5 -- Mesocenozoic faults; 6 -- proposed postglacial "southern" faults discovered by aerial photographs; 7, 8 -- elements of the dislocation system occurring during the Mondy [Mondinskiy] earthquake discovered in 1950 and 1972 respectively (the map symbols are not to scale).

Key:
1. Mondy
2. Irkut

joints located near the rear edges of the high terraces were formed at the time of the main shocks as a result of subsidence of the terrace slopes. In individual places, on steep slopes, traces of landslip-landslide displacements are obvious. The maximum width of the joints reached 1-2 m, and the vertical amplitude of the displacement of the southwestern limb reached 0.3-0.8 m (Fig 65). In some cases the freely recumbent blocks of granite and granito-gneiss were cut off by the joints, which indicates the high concentration and force of the underground shocks. In the central part of the seismic dislocation zone, along the main joint, a block structure was formed (60X300 meters) within the limits of which the amplitude of the lefthand shift reached 10 to 15 cm. Thus, the movement along the fractures was of the slip-fault thrust nature.

Figure 65. Joints occurring in the epicentral zone of the Mondy force 9 (M=6-3/4) earthquake of 4 April 1950. Vertical displacement amplitude 0.8 meters. Photograph by P. M. Khrenov.

The basic zone of seismic dislocations was 1.5 to 2 km from the settlement of Mondy, which fixes the minimum radius of the force 9 tremor.

The Mondy earthquake was accompanied by rockslides noted in the Irkut River canyon 8 to 10 km west and east of the Mondy basin.

All of the brick stoves were destroyed in the settlement of Mondy during the earthquake. In the wooden buildings, the ceiling beams and roofs were destroyed which was caused by their general movement to the northwest. In some wooden houses the corners separated, the walls collapsed, window and doorframes were twisted, vertical columns were broken at a height of 1 to 1.5 meters. Some of the residents felt vertical shocks which was also confirmed by the hurling of individual objects upward. The force of the earthquake reached 9 here.

In Irkutsk (240 km from the epicenter) the seismic macroeffects corresponded to force 5.

With respect to force and macroeffects, the Muya earthquake of 27 June 1957 was the most significant of all of the known ones in Eastern Siberia during the historic time interval and it was the most powerful in the territory of the USSR since 1911. Its magnitude was 7.9 (Rothe, 1969). It was felt over an area of 2 million km^2. The area bounded by the force 5 isoseism corresponded to 600,000 km^2 (Fig 66). The seismogravitational shifts of the ground (landslips, talus) were observed over an area of more than 150,000 km^2 at an epicentral distance of up to 350 km. The force 8 effects were noted at 150 km, and six to seven force effects up to 500 km (Chita, Bodaybo) from the epicenter. With respect to the set

of signs (magnitude, macroseismics, deformation of the mountain, hydrogeological variations), the intensity of the earthquake is reliably determined at force 10-11. With respect to the $M-I_0$ ratio at H=20 km: according to Gutenberg and Richter, force 11, according to Karnik, force 12, according to Shebalin, force 10-11, according to Bune, force 11, according to V. and A. Solonenko, force 11 (see Table 2).

The reconnaissance examination of the Muya earthquake was performed in July 1957, and a detailed ground study was made of the pleistoseismic zone -- in 1962. A detailed description of the results of the examination was published in the available publications (Solonenko, V., 1964b, 1965; ACTIVE TECTONICS..., 1966); therefore we shall limit ourselves to the brief information here.

The epicentral region is associated with the Namarakitskaya embryonic basin of the Baykal type. During the course of the earthquake, the basin dropped a minimum of 5 to 6 meters and shifted to the west, and the adjacent part of the Udokan ridge was uplifted by 1 to 1.5 meters and shifted to the east 1 to 1.2 meters. As a result, a complex system of seismic dislocations occurred with a general extent of about 30 km. Among the seismodislocations, the strike-slip normal faults and the strike-slip thrust faults predominate, but the tension joints also had great significance (to 7 to 8 meters and in one case to 19 meters); the compression traces were "molehills" up to 3.8 meters high. In addition, twisting folds, seismic dome structures, cleavage fractures and so on were documented.

The seismic dislocations are concentrated predominantly on the south side of the basin which reflects its general structure -- one-way graben. The left shift is expressed uniquely not only with respect to the main fractures, but also the feathering joints.

In the western part of the Namarakitskaya basin there is an intrabasin mountain commissure. It served as a counterforce basin shifted to the west, as a result of which an asymmetric anticlinal was formed (Fig 67) transverse to the general strike of the seismic dislocations. The apparent height of the fold is about 4 meters, and it is about 15 meters wide.

A strike-slip fault runs on the north side of the basin after the mountain commissures; in the central part there is a right shift (displacement of 1.05 meters), and on the eastern end, a fault having left shift attributes.

The Udokan ridge was uplifted with respect to the displacer dipping to the south (under the ridge) at an angle of about 70°.

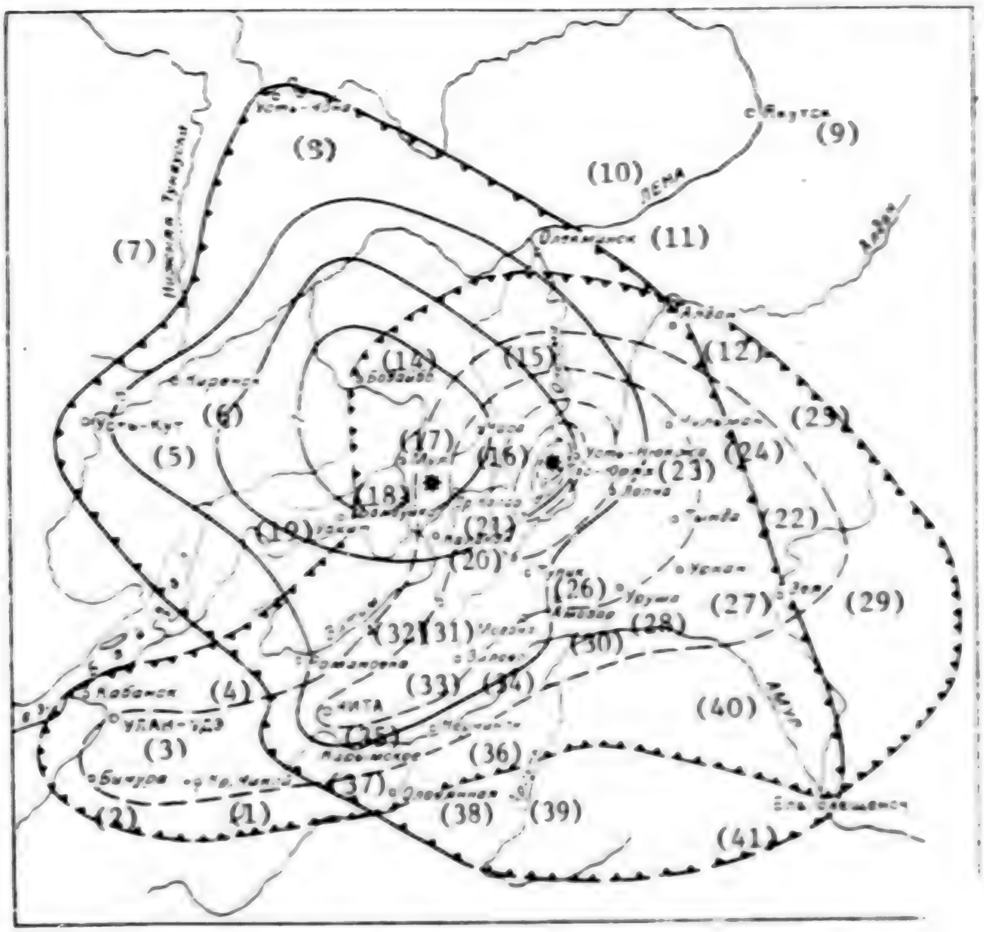


Figure 66. Isoseismal map of the Muya earthquake (M=7.9, I_0=force 10-11) and the Tas-Yuryakhskiy earthquake (M=7, I_0=force 9-10) (the dotted line). The toothed line is the boundary of perceptibility (Kurushin, 1974; Kochetkov, et al., 1975).

Key:

1. Kr. Chikoy; 2. Bichura; 3. Ulan-Ude; 4. Kabansk; 5. Ust'-Kut; 6. Kirensk; 7. Nizhnyy Tutvuska; 8. Ust'-Chona; 9. Yakutsk; 10. Lena; 11. Olekminsk; 12. Aldan; 13. Aldan; 14. Bodaybo; 15. Olekta; 16. Chara; 17. Muya; 18. Bambuyka; 19. Uakit; 20. Kalakan; 21. Sr. Kalar; 22. Tynda; 23. Tas-Yuryakh; 24. Ust'-Nyukzha; 25. Chul'man; 26. Tupik; 27. Urkan; 28. Urusha; 29. Zeya; 30. Amazar; 31. Mogocha; 32. Vitim; 33. Romanovka; 34. Zilovo; 35. Chita; 36. Nerchinsk; 37. Karymskoye; 38. Olovyannaya; 39. Argun'; 40. Amur; 41. Blagoveshchensk

Figure 67. Asymmetric fold west of the Novyy Namarakit Lake formed during the Muya earthquake of 27 June 1957. Photograph by V. P. Solonenko

Figure 68. Novyy Namarakit Lake formed in the subsided part of the Namarakitskaya basin during the Muya earthquake on 27 May 1957. Photograph by V. P. Solonenko.

The Novyy Namarakit Lake (see Fig 68) was formed in the basin as a result of its subsidence. Its maximum length is up to 3.5 km and it is up to 600 meters wide. On examination of the epicentral zone at the end of June 1962, the lake was 3.1 km long, but its level dropped by 1.8 meters. We assumed that this drop was connected with fracture of the above-mentioned anticlinal fold (ACTIVE TECTONICS..., 1966, p 156). Subsequently, the area of the lake was reduced persistently, and by July 1975, it almost disappeared. Inasmuch as there were no hydrologic causes for the disappearance of the lake, its explanation remains as follows: the subsiding basin began to rise after the earthquake. In 1957 it rose approximately 4 meters, and in 1975 the residual deformation dropped from 5-6 meters to 1-2 meters. The phenomena of the return motion of the earth's crust after the earthquake are known also in other highly seismic regions of the earth. Thus, in the case of the Japanese earthquake of 1 September 1923, the shore of the Miura Peninsula rose 7.6 meters, and after the earthquake it gradually dropped 6.1 meters (the stable residual deformation was +1.5 meters).

The extraordinary intensity of the Muya earthquake found reflection in the accompanying phenomena. The passive movement of the walls of the faults was observed to 90 km to the east (in the direction of shift of the Udokan ridge) and 50 km to the west of the epicentral zone.

The groundwater regime changed at great distances. At the Goryachii Klyuch local health resort 180 km from the epicenter, the spring discharge increased, and the temperature of the water rose from 42-43° to 47-48°.

In Chita, the level of the deep groundwater in three wells at the water supply station rose by 2 meters, their discharge increased from 60 to 100 m^3/hour.

The filling of the Toreyskiy lakes was connected with movement of the earth's crust caused by the Muya and, possibly, the Mongolian earthquakes of 1957 (see Chapter I).

The Central Baykal earthquake of 29 August 1959 ($M=6.8$, I_0=force 9) was felt over an area of about 800,000 km^2 (Fig 69). In the epicentral zone of the earthquake, subsidence of a section of the bottom of Lake Baykal by 10 to 15 meters took place along with rejuvenation of the fault bounding the Proval Bay extending about 10 km (Solonenko, V., Treskov, 1960).

The populated places on the east shore of the Proval Bay suffered the most from the earthquake. The earthquake-resistant Siberian log houses were noticeably deformed in many cases (the corners split, and the top beams shifted, and so on), and the stoves and smokestacks were destroyed to the base or rotated around their axis. Cases of nonuniform distribution of the quake intensity on the earth's surface were noted. For example, in the club building of the settlement of Mal. Dulan, there were four stoves lined up in a row 3, 5 and 3 meters apart respectively. The first stove was rotated clockwise 15 to 20° and cracked sharply, but it was

left standing: the second collapsed to its base, and the third received slight damage, and the southwest half of the fourth was destroyed vertically. It is impossible to explain the different degree of damage to the stoves in this case by the difference in soil-hydrogeological conditions in the foundation (Solonenko, V., Treskov, 1960; Solonenko, V., 1962a).

The observations in the vicinity of Irkutsk offer another example of irregular damping of the seismic vibrations more significant with respect to area. The intensity of the quaking varied from 5 to 7 here depending on the local engineering-geological conditions. The central part of the city located on the second terrace of the Angara River and at the foot and on the brow of the third terrace suffered most. About 80 cases of destruction and falling of the stovepipes and partial destruction of the stoves were observed here. Cracks often running all the way through occurred in the walls of the old style stone houses, and the plaster cracked and fell off in pieces. Individual houses were in an emergency condition.

In the upland parts of the city where the structures are on a foundation of thick sandy loam or semirocky soil and the groundwater level is at great depth, the earthquake intensity reached force 5-6.

In the Leninskiy Rayon where loose flooded ground developed, the quake intensity should have been no less than force 8, but in fact it did not exceed force 5. The difference of 3 points between the expected and the true force of the earthquake on 29 August 1959 is explained by an increase in thickness of the "clastic" layer of the Jurassic deposits in the Leninskiy Rayon by 250-400 meters by comparison with the southern parts of Irkutsk (Solonenko, V., 1962a).

The Mogodskoye earthquake occurred in the territory of Mongolia on 5 January 1967. Its intensity reached force 10 (M=7.8).

In the epicentral zone in the territory of Mogod-somon of Bulganskiy Aymak in Mongolia a system of dislocations with a break in continuity occurred consisting of a principal fault (upthrow fault) extending up to 45 km, two large joints subparallel to it and a large number of feathering and accompanying smaller fractures. The maximum amplitude of the uplift of the eastern and northeastern limbs of the mean upthrow is 5 meters. It is characteristic that the compressive and tensile deformations correspond to each other (Natsag-Yum, et al., 1971).

In the territory of the USSR, the earthquake was felt in the southern parts of the Buryat ASSR and in the Irkut Oblast (Fig 70). It reached maximum intensity in Soviet territory in the vicinity of Zakamensk at a distance of about 250 km from the epicenter. Two and three-story buildings were damaged significantly here (there were gaping through cracks in the main walls, collapse of large pieces of plaster). However, such deformations were observed only in buildings constructed without earthquake proofing reinforcing. In structures with earthquake reinforcement no deformations occurred.

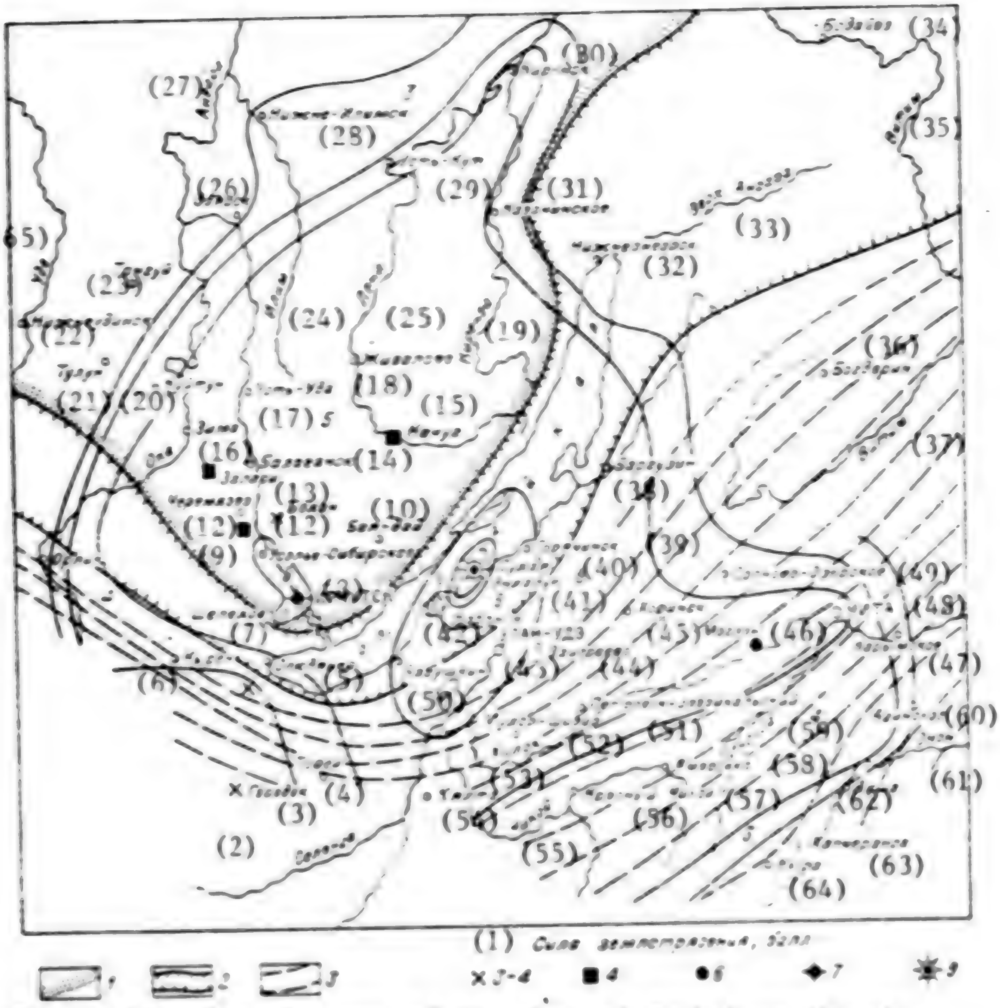


Figure 69. Isoseism map of the Central Baykal earthquake of 29 August 1959. Compiled by V. P. Solonenko
1 -- Siberian platform; 2 -- edge sections of the platform and baykalides activated by the latest movements; 3 -- generalized directions of the basic linear structures; the symbols indicate the force of the earthquake not characteristic of the given area as a whole.

Key:

1. Earthquake force: 2. Selenga; 3. Gorodok; 4. Torey; 5. Slyudyanka
6. Kyren; 7. Shelekhovo; 8. Irkutsk; 9. Usol'ye-Sibirsko; 10. Bayanday;
11. Bokhan; 12. Cheretkhovo; 13. Zalari; 14. Balagansk; 15. Kachug;
16. Zita; 17. Ust'-Uda; 18. Zhigalovo; 19. Kurenga; 20. Kuytun;
21. Tulun; 22. Nizhneudinsk; 23. Tanguy; 24. Ilim; 25. Lena; 26. Zayarsk;
27. Angara; 28. Nizhne-Ilimsk; 29. Ust'-Kut; 30. Kirensk; 31. Kazachinskoye;
32. Nizhneangarsk; 33. Verkh. Angara; 34. Bodaybo; 35. Vitim;
36. Bogdarin; 37. Vitim; 38. Barguzin; 39. Goryachinsk; 40. Sukhaya;
41. Znkhaluk; 42. Kabansk; 43. Ulan-Ude; 44. Zaigrayevo;
45. Khorinsk; 46. Mogzon; 47. Karymskoye; 48. Chita; 49. Sosnovo-Ozerskoye; 50. Babushkin; 51. Petrovsk-Zabaykal'skiy; 52. Mukhor-Shibir; 53. Khilok; 54. Kyakhta; 55. Chikoy; 56. Krasnyy; 57. Chikhoy; 58. Yamarovka; 59. Ingoda; 60. Aginskoye; 61. Onon; 62. Aksha; 63. Khapcheranga; 64. Kyra; 65. Uda.

In Irkutsk, Ulan-Ude, Angarsk and Shelekhov, there was an earthquake of force 5. The local increase in intensity of the quaking to force 6 was observed as a result of favorable ground and hydrogeological conditions. In many of the buildings, the earthquake proofing seams opened up, cracks occurred in the plaster, and so on. In individual cases, through cracks were formed in the main walls and the water lines ruptured.

During the Mogodskiy earthquake, just as in the preceding ones, anomalies were noted in the quaking distribution over the earth's surface. The force 5 isoseism extended to the northwest along the Irkut basin. Within the outline of the force 5 isoseism, in the vicinity of Listvenichoye, there was an "island of seismic calm," within the limits of which the quaking intensity did not exceed force 3-4.

The Tas-Yuryakhskoye earthquake of 18 January 1967 was one of the strongest in the northeastern part of the Baykal rift zone. It occurred near the epicenters of the Nyukzha and the Olekma earthquakes of 5 January and 14 September 1958 (M=6.5, I_0=force 9) and it again irrefutably confirmed, on the one hand, the seismotectonic relation of the two regions -- Pribaykal'skiy and Stanovoy -- and on the other hand, the inconstancy of the seismic conditions. Over the area 500 km^2 where it was possible by the seismic activity calculations to expect force 9 earthquakes no more frequently than once in many thousands of years, in reality two force 9 and one force 9-10 earthquakes occurred in 9 years.

The joint processing of the observation data of the seismic stations of Pribaykal'ye and Yakutia made it possible more precisely to define the position of the epicenter of the earthquake (see Fig 71) and also to estimate the depth of its center; H=13 km. The magnitude (M) of the main shock determined by the data from the teleseismic stations is estimated at 7.0; the energy class (K) is 16; the intensity of the earthquake in the epicenter (with respect to the ratio of M-K-I_0) is force 9-10.

The Tas-Yuryakhsoye earthquake encompassed the broad territory of Southern Yakutia, Chita and the Amur Oblasts and the Buryat ASSR the total area of about 1 million km^2. The gathered macroseismic data made it possible to compile an isoseisal map of this earthquake (see Fig 66), but in some sections, as a result of the absence of populated places and incomplete information the isoseisms were only proposed. This especially pertains to the northern areas outlined by the small force (3-4) isoseisms.

The vicinity of maximum quaking (force 9) exhibited in a comparatively small area (200-250 km^2) along the right bank of the middle course of the Tas-Yuryakh River is basically isolated with respect to the surface exotectonic effects (Kochetkov, et al., 1975). This is predominantly the "jarred" eluvium and talus, the mud flow formations, shearing of the soil and vegetation layer, felling of the forest, numerous sections of broken ice and local debacles, rock falls and small landslips on the steep sides of the Tas-Yuryakh River valley. The seismic acceleration in the epicentral region obviously exceeded one: in the gently sloping sections (to 5°)

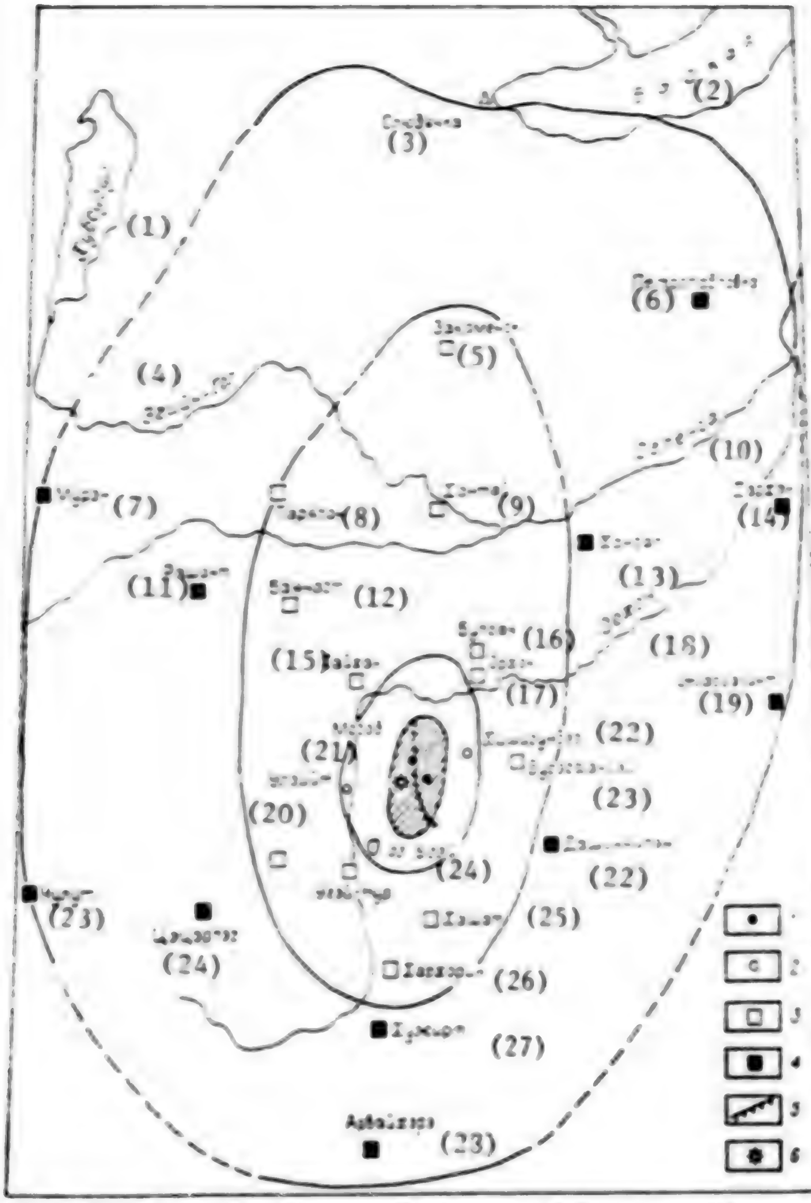


Figure /0. Isoseismal map of the Mogodskoye earthquake of 5 January 1967. Compiled by S. Khil'ko and I. Balzhinnyam.

1-4 -- earthquake intensity at the stations according to macroseismic data, force: 1-9, 2-8, 3-7, 4-6; 5 -- zone of residual seismogenic deformations (seismically active rejuvenated fault); 6 -- instrumentally determined epicenter of the earthquake.

Key:

1. Khubsugul; 2. Baykal; 3. Slyudyanka; 4. Egiyn-Gol; 5. Zakamensk; 6. Petropablovka; 7. Muren; 8. Taryapan; 9. Khantay 10. Selenga; 11. Rashant; 12. Bayanogt; 13. Khangal; 14. Darkhan; 15. Saykhan; 16. Bulgan; 17. Orkhon; 18. Orkhon; 19. Zhargapant; 20. Ulziyt; 21. Mogod; 22. Khishigunder; 23. Burgukhangay; 24. Ugev Lake; 22. Dashinchipen; 23. Chulut; 24. Tsetserpeg; 25. Khashat; 26. Kharkhorin; 27. Khuzhirt; 28. Arbaykhere

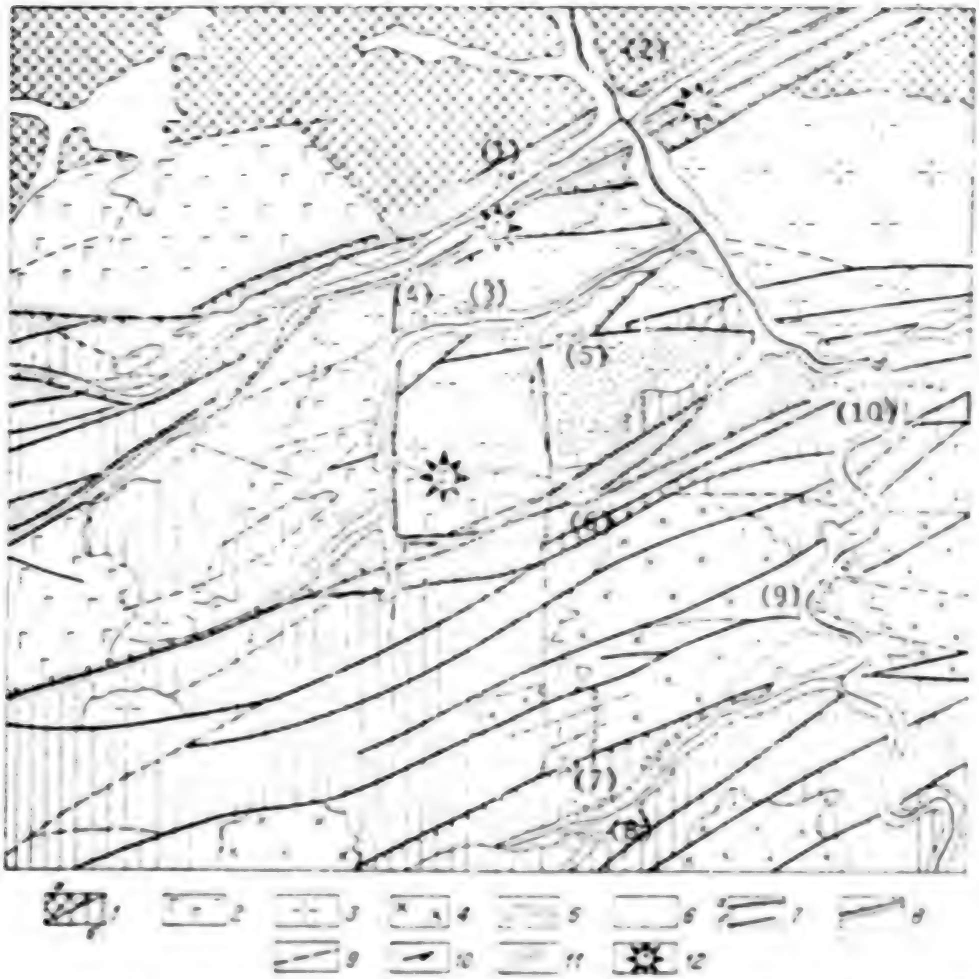


Figure 71. Seismogeological diagram of the epicentral region of the Tas-Yuryakhskiy earthquake on 18 January 1967. Compiled by S. Khil'ko.

1 -- late Archean (a) and early Proterozoic (b) gneisses and crystalline shale; 2 -- gabbro-anorthosite complex (Imangrskiy and Arbagasskiy massifs); 3 -- Proterozoic porphyritic syenites and granite-syenites; 4 -- other granitoids, including mesozoic; 5 -- zones of diaphthorites and diaphthoritic rock; 6 -- alluvial deposits; 7 -- Cenozoic faults clearly expressed in the relief: a -- normal faults and upthrow faults, b -- unclear morphology. I -- Imangrskiy, TYu -- Tas-Yuryakhskiy, SD -- Severo-Dyryndinskiy [Northern Dyrynda], D -- Dyryndinskiy [Dyrynda]; 8 -- zones of activated faults rejuvenated during the strong earthquakes of 1958; 9 -- pre-Cenozoic faults established; 10 -- sections of dislocations with a break in continuity with established shear components; 11 -- areas of surface deformations during the Tas-Yuryakhskiy earthquake; 12 -- epicenters of strong earthquakes (force 9-10) in the Olekma epicentral zone, numbers on the diagram: 1 -- Olekma, 1958; 2 -- Nyukzha, 1958; 3 -- Tas-Yuryakh, 1967.

Key:

1. Imangra; 2. Chebarkas; 3. Tas-Yuryakh; 4. I; 5. TYu; 6. SD; 7. D; 8. Dyryn-Yuryakh; 9. Olekma; 10. Ust'-Nyuzha

there were large blocks up to 120 tons that flew up, turned over and fell inth eir "holes" on the side or on their "tops" (they roll down the steeper slopes).

Numerous data indicating quakes of force 8 and 7 were gathered in the unique, very large settlement of Ust'-Nyukzha 35 km east of the earthquake epicenter and also in the winter camps and tent villages of the reindeer herdsmen located near it within a radius of on the order of 40 km. The sharp vibration of the ground was accompanied by a loud roar of low tones, rocking of the trees, rockfalls, breaking and piling up of the ice on the Olekma and Imangra Rivers. The observations of the local hydrometeorological station indicate a sharp rise (to 15 cm) and fall (to 6 cm) of the water in the Olekma River during the earthquake.

The force 6 effects were noted at a distance of 80-90 and 180-200 km from the epicenter. People ran out of their houses in panic, they found it difficult to stand up, vibrations were felt while walking, the noise of avalanches and falling of rock was noted on both sides of the Olekma, Nyukzha and Tas-Yuryakh Rivers.

In many populated areas hundreds of kilometers from the epicenter of the microseismic effects were accompanied by force 5 quaking. Explicit nonuniformity of distribution of the quaking with respect to area is noted here. For example, identical effects were noted in the settlements of Srednyaya Olekma (110 km from the epicenter), Ust'-Urkima (180 km), Sredniy Kalar (225 km), Urusha (290 km), Ksen'yevskaya (350 km), Usugli (550 km). Moreover, in Chita at distance of 675 km from the epicenter the earthquake was felt with a force exceeding force 5: deformations of modern buildings were observed, and one case of destruction of a wooden building was recorded.

Still greater nonuniformity was noted in the distribution of the force 4 to 3 quakes. Here the isoseisms extend in two directions: far to the southwest, to Baykal, and to a lesser degree to the east and southeast, encompassing the settlements of Unkha, Ogoron and the city of Zeya and Blagoveshchensk (850 km from the epicenter) where serious deformations occurred in several high rise brick buildings ready for occupancy.

This clearly expressed asymmetry in the quake distribution during the Tas-Yuryakh earthquake can, on the one hand, be explained by the peculiarities of the deep structure of the territory. Actually, the orientation of the isoseisms extended to the west and southeast coincides in the first approximation with the structural-tectonic boundary between the baykalides and Hercinides. On the other hand, the appearance of a zone of increased force at great distances (Chernyshevsk, Usugli, Chita, Blagoveshchensk) can be connected with peculiarities of engineering-geological structure of such regions and the propagation of seismic vibrations. However, it is impossible to not mention that the spread of the perceptible quaking to the southwest 470 km farther from the epicenter than in the Muya earthquake remains a mystery.

The Melichanskoye earthquake of 8 October 1974. Although this earthquake is entirely routine for Eastern Siberia ($M=5.2$, $K=13$, I_0=force 7), it deserves special attention, for it occurred on the platform, in a region considered aseismic. The quaking encompassed the Lenskiy, Vilyuskiy and Olekminskiy [Olekma] Rayons of the Yakut ASSR and the northern areas of the Irkutskaya [Irkut] and Amurskaya [Amur] Oblasts. The Pleistoseismal region of the earthquake was located in the headwaters of the Melichan River, the right tributary of the Biryuk River falling into the Lena 50 km above Olekminsk.

By the results of the macroseismic examination of the consequences of this earthquake, the isoseismal map shown in Fig 72 was compiled.

The force 5-6 effects were observed at the meteorological station of Kiliyev (at an epicentral distance of 50 km) and at the lineman's station of Ergedzhey (85 km) of the Lensk-Suntary telephone line. The earthquake began with a shock of an "explosive nature," The quaking was felt even in the open air while walking. The vibrations lasted 30 seconds. Cracks appeared in the buildings and plaster fell off the walls.

Force 5 effects were noted in the settlements of Daban (75 km), Neryuktey-I (about 80 km), Chapayevo (100 km), Bysbttakh (110 km). The vibrations resembled the effect created by a heavy tractor passing the house. The logs in the houses cracked, and in places plaster fell off the walls. In the village of Daban on the bank denudations of the Lena made up of sandy loams, small subsidence joints were formed.

The force 5-6 quakes were felt at a distance of 95-165 km in the settlements of Tinnaya, Kochegarovskaya, Del'geyskaya, Abaga, Turukta, Tokko, Yuzh. Nyuya, Saldykel' and Batamay. The crackling of the log huts was heard. The vibrations resembled the effect created by a heavy truck passing the house.

Force 4 quakes encompassed the city of Olekminsk, Lensk, the settlements of Unkyur, Macha, Solyanka, Dzhikimde (105-270 km). The squeaking of the logs, and the rattling of the windows and dishes could be heard.

The information about the force 3 earthquakes was obtained from the seismic stations in the settlements of Bodaybo and Chara.

The presented data indicate the nonuniformity of the seismic vibrations -- they were propagated far to the south, but they were sharply damped in the north. From the epicenter to the settlements of Bodaybo and Chara, where an earthquake of force 3 was felt, it was 400 and 425 km. In the settlements of Suntary and Kempendyay located 140 to 160 km to the north of the epicenter, the earthquake was not felt.

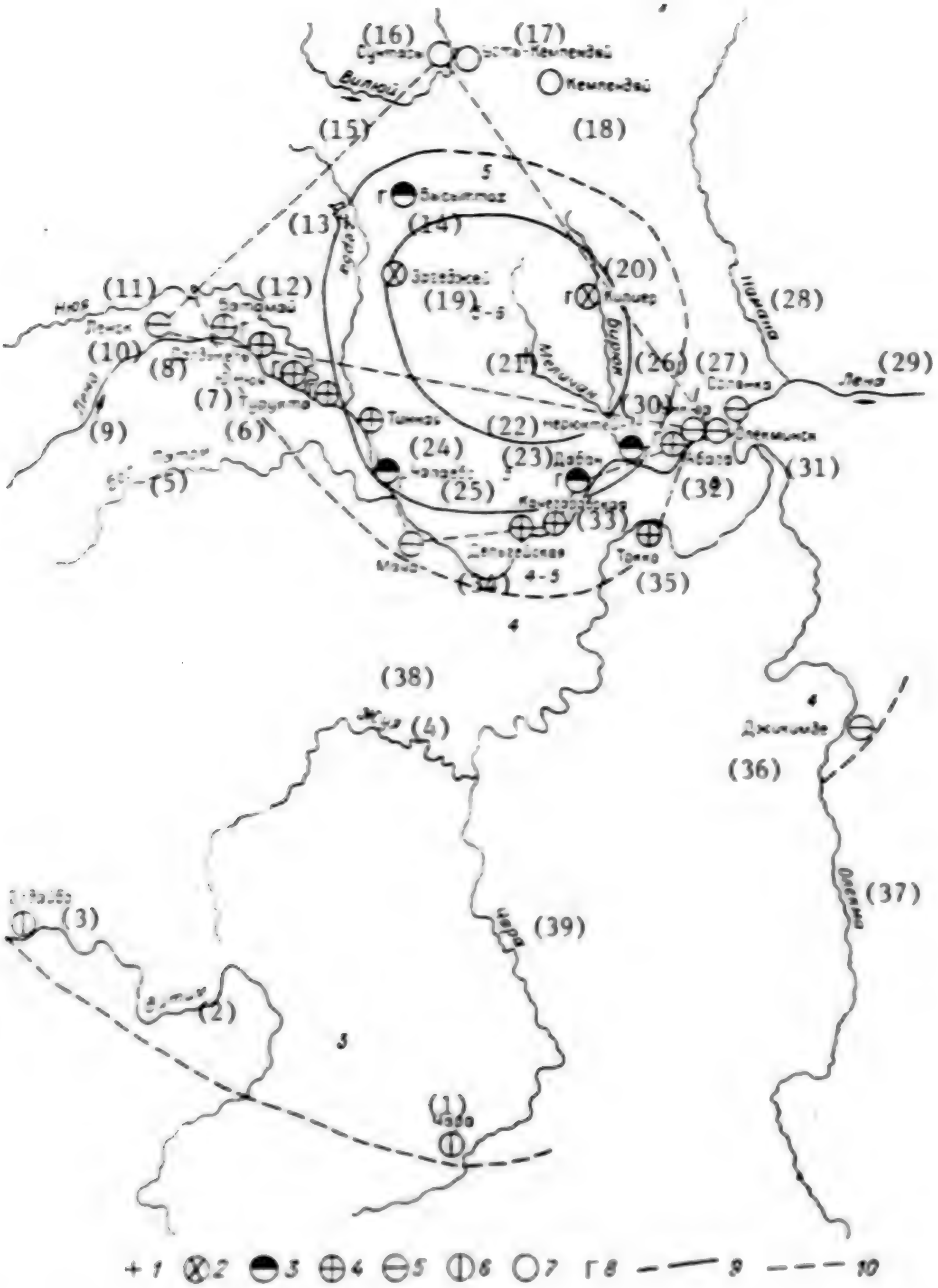


Figure 72. Isoseismal map of the Melichanskiy [Melichan] earthquake of 8 October 1974.
Compiled by A. D. Abalakov, T. M. Kozyrev.
1 -- epicenter according to the instrument data; 2 -- force 5-6; 3 -- 5; 4 -- force 5; 5 -- 4; 6 -- force 3; 7 -- not felt; 8 --populated areas where the roar was heard; 9 -- isoseisms; 10 -- examination route; The numbers indicate the force period.
[See key on p 219]

[Key to Fig 72, p 218]:

1. Chara; 2. Vitim; 3. Bodaybo; 4. Zhuya; 5. Bol. Patom; 6. Turukta; 7. Yu. Nyuya; 8. Saldykel'; 9. Lena; 10. Lensk; 11. Nyuya; 12. Batamay; 13. Dzherba; 14. Bysyttakh; 15. Vilyuy; 16. Suntary; 17. Ust'-Kempendyay; 18. Kemlendyay; 19. Ergedzhey; 20. Kipiyer; 21. Melichan; 22. Neryuktey; 23. Daban; 24. Tinnaya; 25. Chapayevo; 26. Biryuk; 27. Solyanka; 28. Namana; 29. Lena; 30. Unkyur; 31. Olekminsk; 32. Abaga; 33. Kochegarovskaya; 34. Del'geyskaya; 35. Tokko; 36. Dzhikimde; 37. Olekma; 38. Zhuya; 39. Chara

In tectonic respects, the pleistoseismal region of the earthquake is associated with the southern edge of the Siberian platform and is located in the territory of the Berezovskiy marginal trough (Fig 73). A sharp bend of the crystal bed of the foundation is observed here (more than 3 km per 30 km of linear extent) with which the zone of the Kempendyaysko-Batatamanskiy structure forming fault is coupled. According to the data from the deep seismic sounding performed by A. I. Yanis and G. D. Batayan through the Mirnyy-Russkaya Rechka profile, this fracture is deep. It intersects the Moho boundary and is traced in the upper mantle to a depth of more than 45 km. The roof of the crystalline foundation is downthrown more than 3 km along the fault. The thickness of the earth's crust over the extent of the route varies from 25.2 km in the uplifted Namaninskiy block to 33 km in the downthrown Kempendyayskiy block.

In addition, near the epicenter of the earthquake, the coupling of the latest uplifts of the activated folded and platform oblasts with the Cenozoic Berezovskiy foothills trough occurs (see Fig 73).

From the macroseismic data, three peculiarities of the strong earthquakes of ancient Siberia important to the seismic regionalization follow.

1. The area encompassed by the quakes, including the destructive ones is anomalously large by comparison with the earthquakes with equal M(K) and I_0 in the Caucasian and Central Asian seismic regions.

This is possible to explain by the predominance in the seismic regions of crystalline rock and the presence of permafrost having low capacity for "extinguishing" the seismic waves.

2. The spread of the quakes is sharply expressed and nonuniform. The classical maps with elliptic isoseisms with approximately equal distance between adjacent isoseisms are far from true. Therefore all the calculations based on the isoseismic maps (depth of center, M, I_0) are highly doubtful. Obviously, the procedure for determining the parameters of the earthquake by the isoseismal areas will be valid. They are more or less identical for earthquakes with equal M(or K) and I_0.

3. In the areas made up of thick loose series (basins made up of Mesocenozoic sediments), the intensity of the earthquakes decreases sharply (sometimes by force 2-3), which in the case of regionalization permits the normative force to be reduced at least by one.

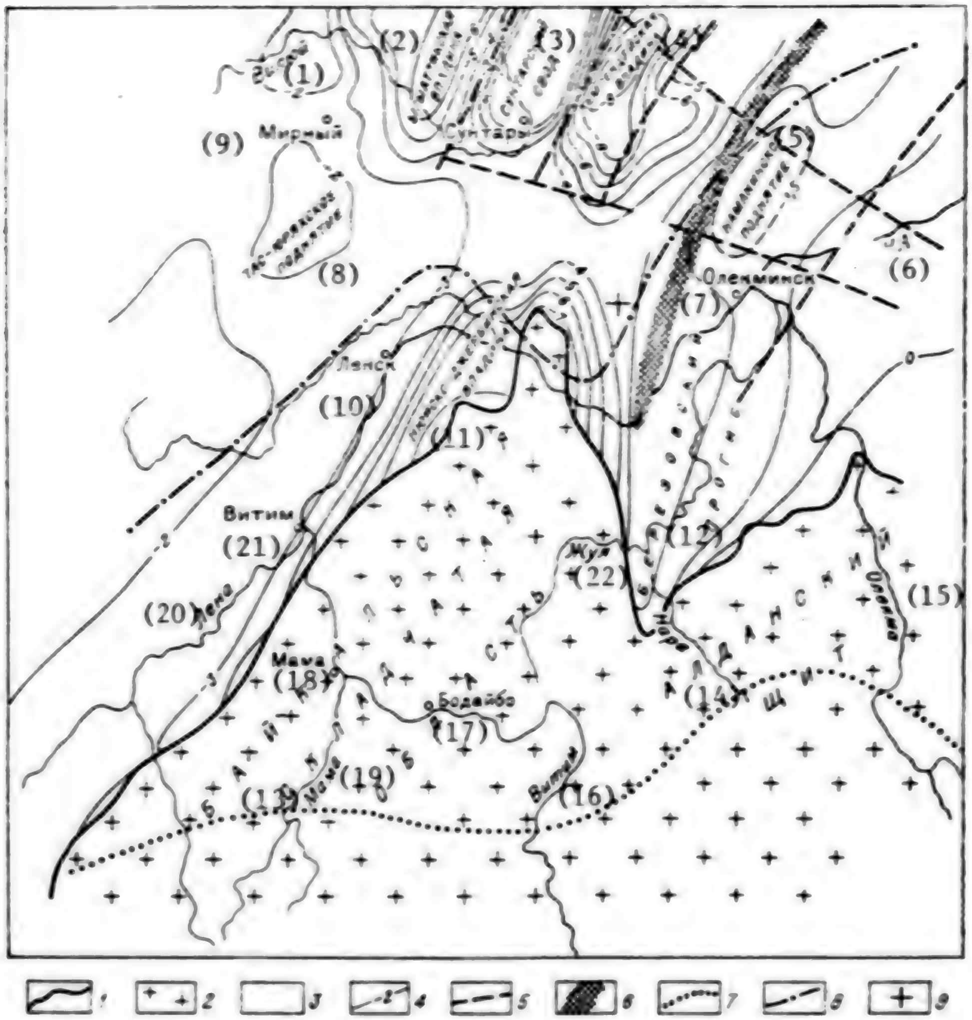


Figure 73. Schematic of the tectonic structure of the marginal structures of the Siberian platform of the vicinity of the Melichan earthquake of 8 October 1974. Compiled by A. D. Abalakov using the structural map of the Siberian platform edited by A. A. Trofimuk and V. V. Semenovich, 1972.

1 -- boundaries of the folded regions and emergence of crystalline rock to the surface; 2 -- crystalline (folded) rock; 3 -- sedimentary rock (platform mantle); 4 -- isohypses of the crystalline foundation; 5 -- fractures (differentiated); 6 -- Kempendyaysvo-Batamanskiy structure forming fracture (according to the geophysical data); 7 -- boundaries of the rift zone; 8 -- boundaries of the latest uplifts; 9 -- earthquake epicenter

Key:

1. Vilyuy; 2. Ygyattinskaya basin; 3. Suntarskiy arch; 4. Kemendyayskaya basin; 5. Namaninskoye uplift; 6. Lena; 7. Olekminsk; 8. Tas-Yuryakhskoye uplift; 9. Mirnyy; 10. Lensk; 11. Nyuysko-Dzherbinskaya basin; 12. Berezovskiy trough; 13. Baykal folded region; 14. Aldan shield; 15. Olekma; 16. Vitim; 17. Bodaybo; 18. Mama; 19. Mama; 20. Lena; 21. Vitim; 22. Zhuya.

CHAPTER VIII. ANALYSIS OF THE EPICENTRAL FIELD. SEISMIC ACTIVITY

Distribution of the Earthquake Epicenters with Respect to Area

A number of papers are devoted to the analysis of the seismicity of Pribaykal'ye in the previous phase of the investigation (Mushketov, Orlov, 1892; Popov, 1939; ATLAS..., 1962; EARTHQUAKES IN THE USSR IN 1962-1970; Solonenko, V., 1950; Treskov, Pshennikov, 1961; VOPROSY SEYSMOTEKTONIKI [Problems of Seismotectonics], 1960; VOPROSY SEYSMICHNOSTI SIBIRI [Problems of the Seismicity of Siberia], 1964; ZHIVAYA TEKTONIKA [Active Tectonics]..., 1966; Solonenko, V., Treskov, 1967; SEYSMOTEKTONIKA [Seismotectonics]..., 1968; BAYKAL'SKIY RIFT [Baykal Rift], 1968).

The discussion of the results obtained recently basically when studying the 10 years of observations (1962-1971) of the modern network of seismic stations in Pribaykal'ye organized at the beginning of the 1960's is the object of further discussion. The practical work was done by the co-workers of the laboratory regional seismicity of the Institute of the Earth's Crust of the Siberian Department of the USSR Academy of Sciences.

First of all, the problem of the distribution of the epicenters of the earthquakes with respect to area deserves attention. Fig 60 shows the distribution of the strongest known shocks. Just as the weak earthquakes, they are classified with respect to energy classes in accordance with the T. G. Rautian scale.

The general location of the epicenters of the weak earthquakes (see Fig 74) is analogous to the location of the epicenters of the strong earthquakes (see Fig 60). In order to obtain quantitative characteristics of the seismicity, according to the data of 1962-1971 (see Fig 74) maps of the densities of the earthquake epicenters (Fig 75) and seismic activity (Fig 76) were constructed. Since there is much that is similar in the isoline configurations on these maps, it is expedient to describe them jointly. When constructing the map of the epicenter density, data were used on the earthquakes from the 9th energy class, just as on the above-described epicenter map. The calculation of the total number of earthquake epicenters of all classes beginning with the 9th was carried out

over areas with the sides 0.2° with respect to latitude and longitude. During the calculations the area was successively shifted by 0.1° both with respect to latitude and with respect to longitude. The values of the epicenter densities are for an area of 100 km^2 and 1 year.

The map of the seismic activity characterizes the number of earthquakes of the 10th energy class over an area of 1000 km^2 per year. When constructing the maps, the temporary intensifications of the seismic activity were excluded insofar as possible. Out of each group of dependent earthquakes, only the strongest shock was taken into account. Inasmuch as the exclusion of the aftershocks of the strong earthquakes encounters special difficulties, when compiling the seismic activity map in the vicinity of the Tas-Yuryakhskiy earthquake of 1967 (the northeast flank of the Baykal rift zone) and the Kodar earthquake of 1970 (in the Kodar ridge) the activity was calculated not for 10 years but for the time periods to the corresponding main shocks. In contrast to this, when calculating the epicenter density map the aftershocks were excluded by comparison with the earthquake background before the main shocks.

The calculation of the seismic activity map with respect to the basic field of the epicenters was performed by the summation procedure (Riznichenko, 1964a) with constant detail (for constant averaging areas 0.4° with respect to latitude and longitude with overlap of the adjacent areas by 0.2°). In order that the isolines of the map not be unjustifiably detailed in the areas with a small number of recorded earthquakes (along the edges of the main epicentral field in the rift region) in cases where less than three epicenters fall in an area, the calculations of the activity were realized by the method of summation with constant accuracy (Gorbunova, Riznichenko, 1965) and assignment of three epicenters on a circular plot.

The high value of the activity obtained for the central part of the Ikatskiy ridge does not reflect the mean long term conditions and is caused by imperfection of the procedure used to exclude the earthquake swarms, especially in the case of this extraordinary, long-lasting swarm. Therefore in the map insert a version of the isolines of seismic activity is presented for this small area according to the data for the last 2 years (1970-1971) when the activity was noticeably lower here.

In addition to the seismic activity map described above, for the same decade an analogous activity map was constructed (see Fig 77) by the complete data on the earthquakes beginning with energy class 9 (that is, with inclusion of all the shocks making up the swarms, aftershocks and groups). The procedure for constructing it was distinguished only by the fact that in the given case and with a small number of earthquakes in the elementary areas (0.4X0.4° with subsequent shift by 0.2°) the calculation was performed by the summation method with constant detail. The angular coefficient of the recurrence rate graph in both cases was taken as the same (-0.5) average for Pribaykal'ye.

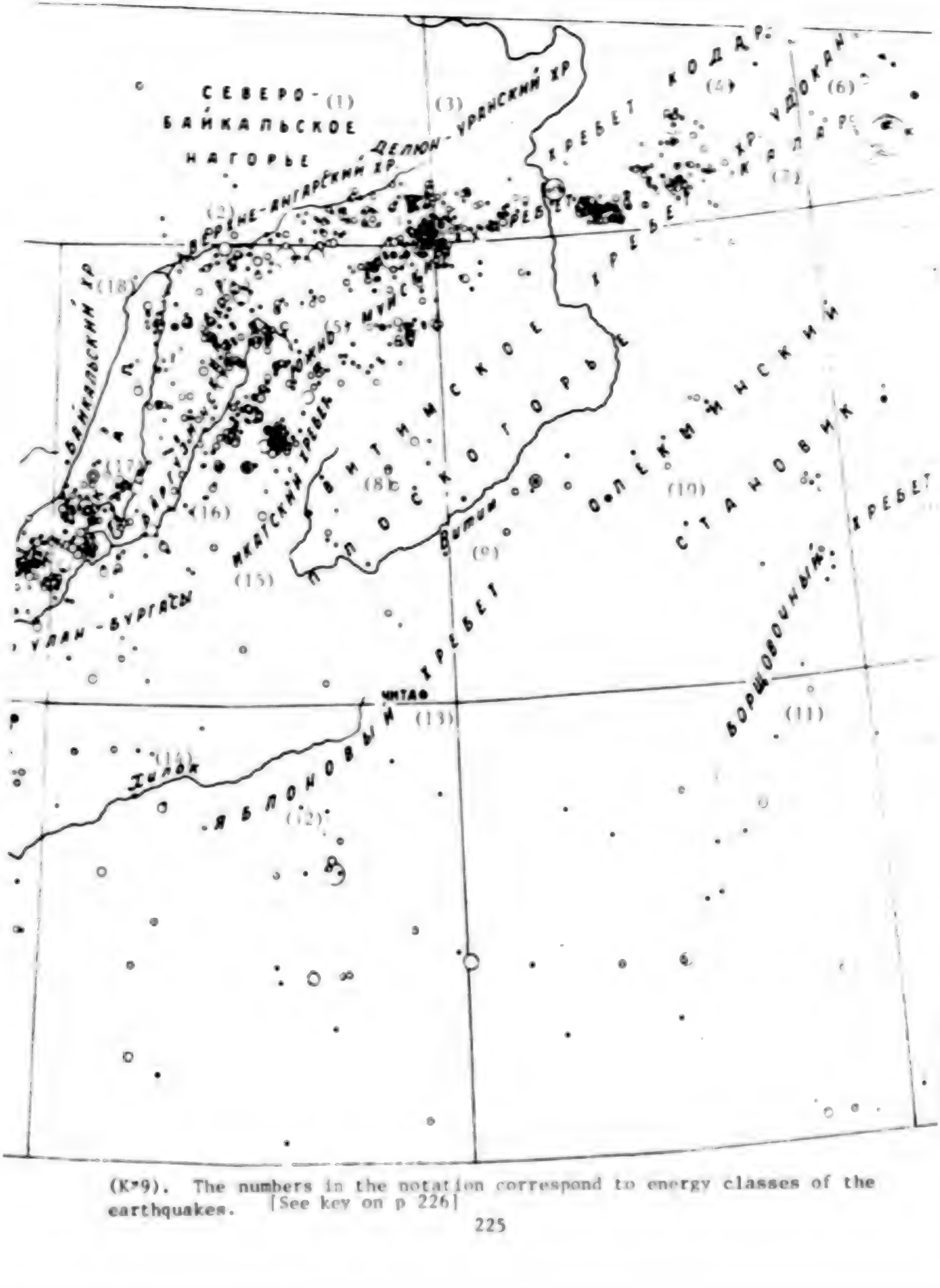
The general configuration of the isolines on both maps is very similar. It is natural that on the map constructed by the complete data, the activity level in many cases turns out to be higher and new areas of increased activity are also detected (in Central Baykal, in the vicinity of the north end of the Barguza ridge, in the Bauntovskaya basin, on the Kodar ridge, and so on) caused by earthquake forms and the sequences of aftershocks.

On the maps of epicenter density and seismic activity, as comparison of them with the initial epicenter map indicates, some of the important structural features of the epicentral field disappear as a result of averaging. From Fig 74 it is obvious that in a number of cases the epicenters of the earthquakes form extended strips bounding the aseismic or low seismic blocks of the earth's crust. The activity map, for the construction of which special attention was given to the preservation of these peculiarities of the epicentral field, is presented in Fig 78. The values of the seismic activity of the isolated zones indicated on it were estimated in accordance with the definition of A_{10} using the map in Fig 74. The solid lines in Fig 78 bound the certainly isolated zones, and the dotted lines, the ones established most rel.ably.

As follows from Fig 78, the bands of the earthquake epicenter are oriented along the zone of the main Sayan fault and its branches (A_{10} is only several hundredths), with respect to Southern and Central Baykal (A_{10} to 0.75), in the northeastern direction through the Barguzia region (to 5 bands, some of them obliquely cut the Barguza and Ikatskiy ridges, A_{10} are measured in tenths). Three bands, converging, continue still farther to the northeast. On the northeastern flank of the Baykal rift another band is noted. The bands of quite sparse epicenters intersect the Vitim plateau (A_{10}~0.03). The active bands on the southwestern flank of the seismic zone are oriented meridionally in accordance with the geological structure.

The isolated bands do not always agree with the known fault zones. The seismicity of the large faults established according to the geological signs, is often low or it is exhibited only in individual sections (the Tunkinskiy fault). Sometimes the presence of bands possibly indicates the occurrence of new active zones still not finding defined geomorphological expression (for example, along the southeastern side of the Barguzinskaya basin). The areas of the mountain commissures between the basins in the northeastern part of the Baykal rift are distinguished by increased seismicity; in the southwest, lowered. The structure of the upper central zone of the earthquakes of Pribaykal'ye [the Baykal region] and Transbaykal was analyzed in more detail in the paper by S. I. Golonetskiy (1976).

Fig 74. Map of the earthquake epicenters of Pribaykal'ye for 1962-1971 [See key on p 226]



(K≥9). The numbers in the notation correspond to energy classes of the earthquakes. [See key on p 226]

[Key to Fig 74, pp 224-225]:

1. Northern Baykal Highland; 2. Upper Angara ridge; 3. Delyun-Uranskiy ridge; 4. Kodar ridge; 5. Southern Muya ridge; 6. Udokan ridge; 7. Kalar ridge; 8. Vitim plateau; 9. Vitim; 10. Olekma Stanovik; 11. Borshchovochnyy ridge; 12. Yablonovyy ridge; 13. Chita; 14. Khilok; 15. Ikatskiy ridge; 16. Barguzinskiy ridge; 17. Baykal; 18. Baykal ridge; 19. Ulan-Burgasy ridge; 20. BAM; 21. Ulan-Ude; 22. Primorskiy ridge; 23. Irkut; 24. Irkutsk; 25. Khamar-Da ridge; 26. Gusinoye Lake; 27. Dzhida; 28. Dzhidinskiy [Dzhida] ridge; 29. Selenga; 30. Buren-Nuru 31. Bulnay Nuru ridge; 32. Khubsugul Lake; 33. Vostochnyy Sayan [Eastern Sayan]; 34. Iya; 35. Oka; 36. Angara; 37. Lena.

The manifestations of the seismic process in the Baykal seismic zone are varied. The earthquake swarms often occur in the Barguzinskiy Rayon, in the Kodaro-Udokanskiy Rayon, in the vicinity of the Upper Muya-Muyakan basins, along the Obrucheskiy fault zones in Central Baykal and the meridional part of the Shurmansko-Shutkhulayskiy fault in the extreme southwest. The earthquake swarm in the Ikatskiy ridge lasting several years is unique. As a rule, the locations of the swarms did not repeat during the instrument seismological observation times. Sometimes the swarms occurred in practice at the same places where at another time seismic process developed fifferently -- a strong earthquake was accompanied by a series of aftershocks (Golenetskiy, et al., 1973).

Depths of the Pribaykal'ye Earthquake Centers[1]

On the basis of the quite broad observations of the earthquakes of Pribaykal'ye, it is possible to state with certainty that their centers are located in the earth's crust. However, the exact establishment of the depths of the centers within the limits of the earth's crust encounters great difficulties primarily as a result of insufficient density of the seismic station network. As a rule, the depth of the center of an individual earthquake with the existing network of seismic stations in Pribaykal'ye cannot in the majority of cases be established with the necessary accuracy. Therefore it is necessary to be satisfied with only a few average estimates. There are several paths for obtaining such estimates.

1. Comparison of Average Hodographs of the Head Waves P for Explosions and Earthquakes

By the observations of more than 20 industrial explosions from the areas of Cheremkhovo and Zheleznogorsk, the apparent velocities and initial ordinates of the average hodographs of the head waves P were determined.

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[1]The greater part of the factual data for the given section was prepared by E. A. Tret'yak.

They turned out to be equal to 7.9±0.05 km/sec and 6.9±0.4 sec respectively. The calculations of the hodographs of the same waves for the earthquakes with an intensity of more than 200 in various versions (in particular, for different parts of the seismic zone) gave somewhat different values, but values close to those that were obtained by the explosions. If we consider that the average thickness of the earth's crust along the routes in Pribayka'ye does not change sharply according to the seismologic data and the deep seismic sounding data, then the indicated closeness of the elements means that the centers of the earthquakes are shallow for the most part (they are located in the upper 5 to 10 kilometer layer).

2. The construction of the earthquake distributions with respect to depths according to the formula for the travel time of the head waves is

$$t_P = (2H - h)\sqrt{\frac{1}{V^2_{\bar{P}_{cp}}} - \frac{1}{V^2_P}} + \frac{\Delta}{V_P} \quad (1)$$

Key:
 1. mean

or excluding the center time, by the formulas for the differences in time of arrival of the direct wave ($\bar{P}$ or $\bar{S}$) and the head wave P:

$$\bar{P} - P = \frac{\sqrt{\Delta^2 - h^2}}{V_{\bar{P}}} - (2H - h)\sqrt{\frac{1}{V^2_{\bar{P}_{cp}}} - \frac{1}{V^2_P}} - \frac{\Delta}{V_P};$$

$$\bar{S} - P = \frac{\sqrt{\Delta^2 - h^2}}{V_{\bar{S}}} - (2H - h)\sqrt{\frac{1}{V^2_{\bar{P}_{cp}}} - \frac{1}{V^2_P}} - \frac{\Delta}{V_P}.$$

where h is the desired depth of the center; $V_{\bar{P}_{mean}}$ is the mean velocity of the longitudinal waves in the earth's crust; V_P, $V_{\bar{P}}$, $V_{\bar{S}}$ are the known propagation rates of the P, $\bar{P}$ and $\bar{S}$ waves; Δ is the epicentral distances determined on establishment of the epicenter, H is the mean thickness of the crust in the region (H=38 km is given for the calculations).

The distributions obtained indicate the small mean depths of the centers and the very significant dispersion of the results as a result of the random errors (Fig 79).

The calculations encompass the observations for January-June 1971 of the earthquakes from the various parts of Pribaykal'ye. The propagation routes of the seismic waves were not differentiated in this case, just as the data from the individual stations were not isolated.

Figure 75. Earthquake epicenter density map for 1962-1971 with K≥9.

[Key to Fig 75, pp 228-229]:

1 -- Uda; 2 -- Iva; 3 -- Oka; 4 -- Irkutsk; 5 -- Lake Kasogol ;
6 -- Orkhon; 7 -- Selenga; 8 -- Khamar-Daban Ridge; 9 -- Ulan-Ude;
10 -- Ulan-Burgasy ridge; 11 -- Primorskiy ridge; 12 -- Angara;
13 -- Northern Baykal Highland; 14 -- Lena; 15 -- Angarskiy ridge;
16 -- Vitim; 17 -- Delyun-Uranskiy ridge; 18 -- Kodar ridge;
19 -- Udokan ridge; 20 -- Baykal'skiy ridge; 21 -- Uda; 22 -- Vitimskoye;
23 -- Ploskogor'ye; 24 -- Khilok; 25 -- Chikoy; 26 -- Yablonovyy ridge;
27 -- Onon; 28 -- Olekma; 29 -- Olekminskiy; 30 -- Sianovik;
31 -- Shilka; 32 -- Gazimur; 33 -- Nerchinskiy ridge; 34 -- Argun';
35 -- MNR; 36 -- KNR

3. Construction of the distributions based on observations of the travel time of the head waves to the individual stations, as in the preceding item, but using more substantiated values of the mean thickness of the crust with respect to the deep seismic sounding profile of the Central Baykal to the Barguzinskaya basin.

The histograms constructed by the data for 1962 to the middle of 1972 (Fig 80) are similar to the graphs from the preceding item.

Obviously, the greatest accuracy in estimating the depth of the center can be achieved by using the known values of the thickness of the crust (for example, according to the deep seismic sounding data) and observations of the waves reflected from the top of its foot. These estimates of the depths of the centers turned out to be possible for the aftershock of the Central Baykal earthquake of 1959 for which in many cases reflected transverse waves were recorded at the seismic station of Bayanday, and in the region close to it where the wave reflection points were located, an independent determination of the thickness of the earth's crust was made by the deep seismic sounding procedure. The calculation of the depth of the centers h were performed in the given case on the basis of the expression

$$(2H-h)^2+\Delta^2=\left(V_r\delta t+\frac{V_r}{V_s}\sqrt{\Delta^2+h^2}\right)^2,$$

where V_r is the mean velocity of the reflected wave in the earth's crust, δt is the difference in times of arrival of the reflected and direct waves. The results of the calculations were formed by the histogram (see Fig 80, e), and they indicate that the depth of the aftershocks of the Central Baykal earthquake of 1959 is quite shallow.

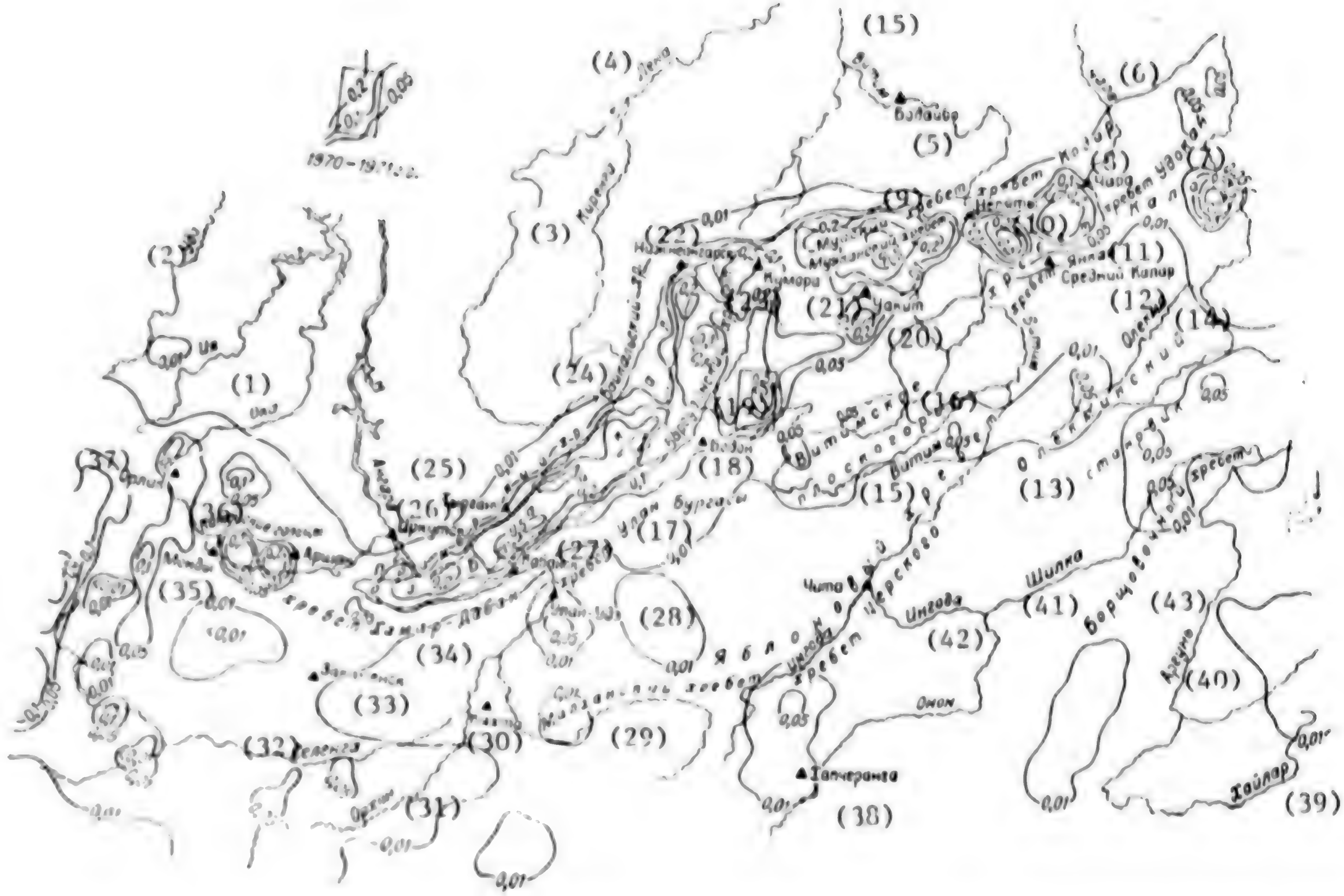
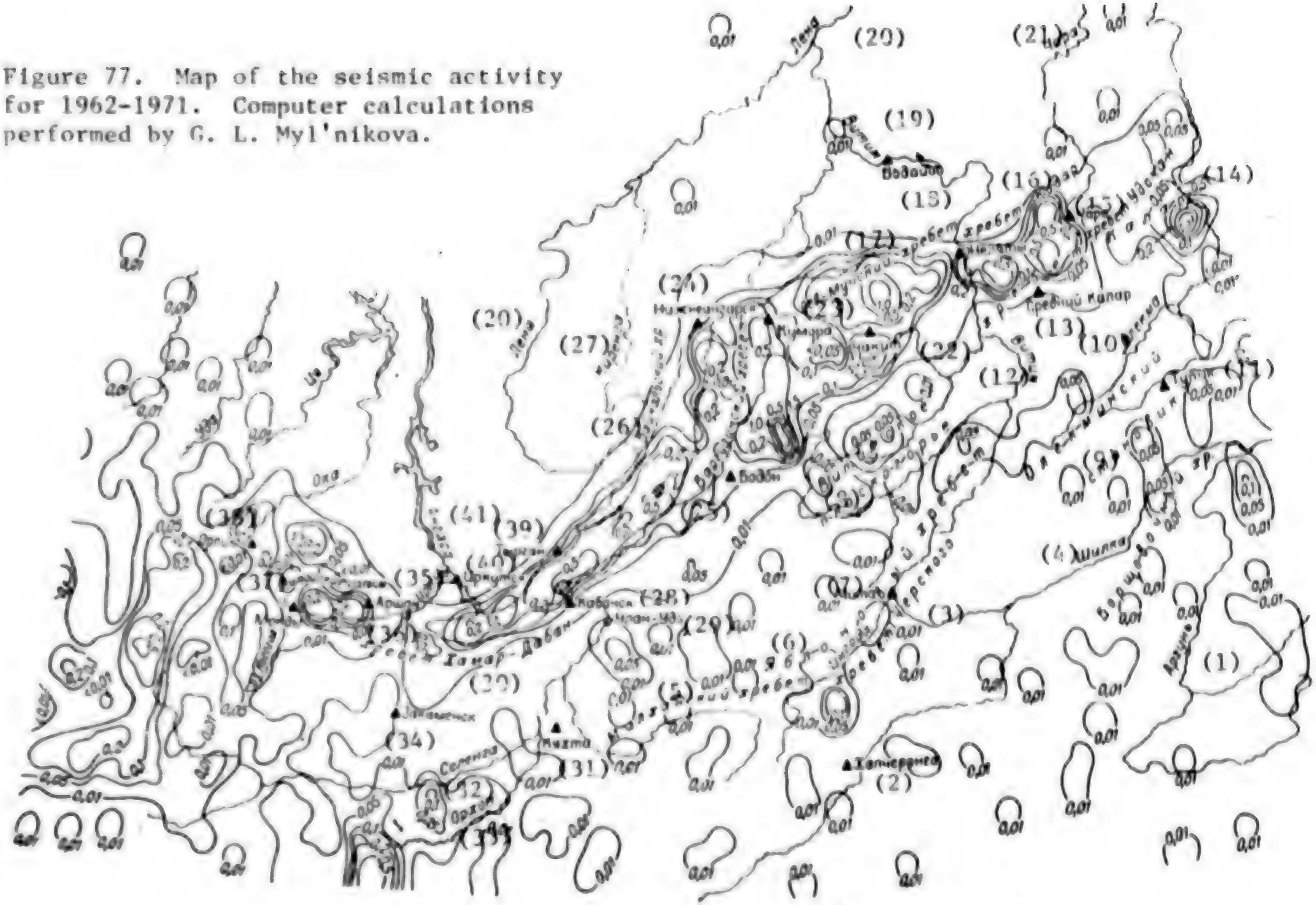


Figure 76. Map of the seismic activity for 1962-1971. Computer calculations performed by G.L. Myl'nikova

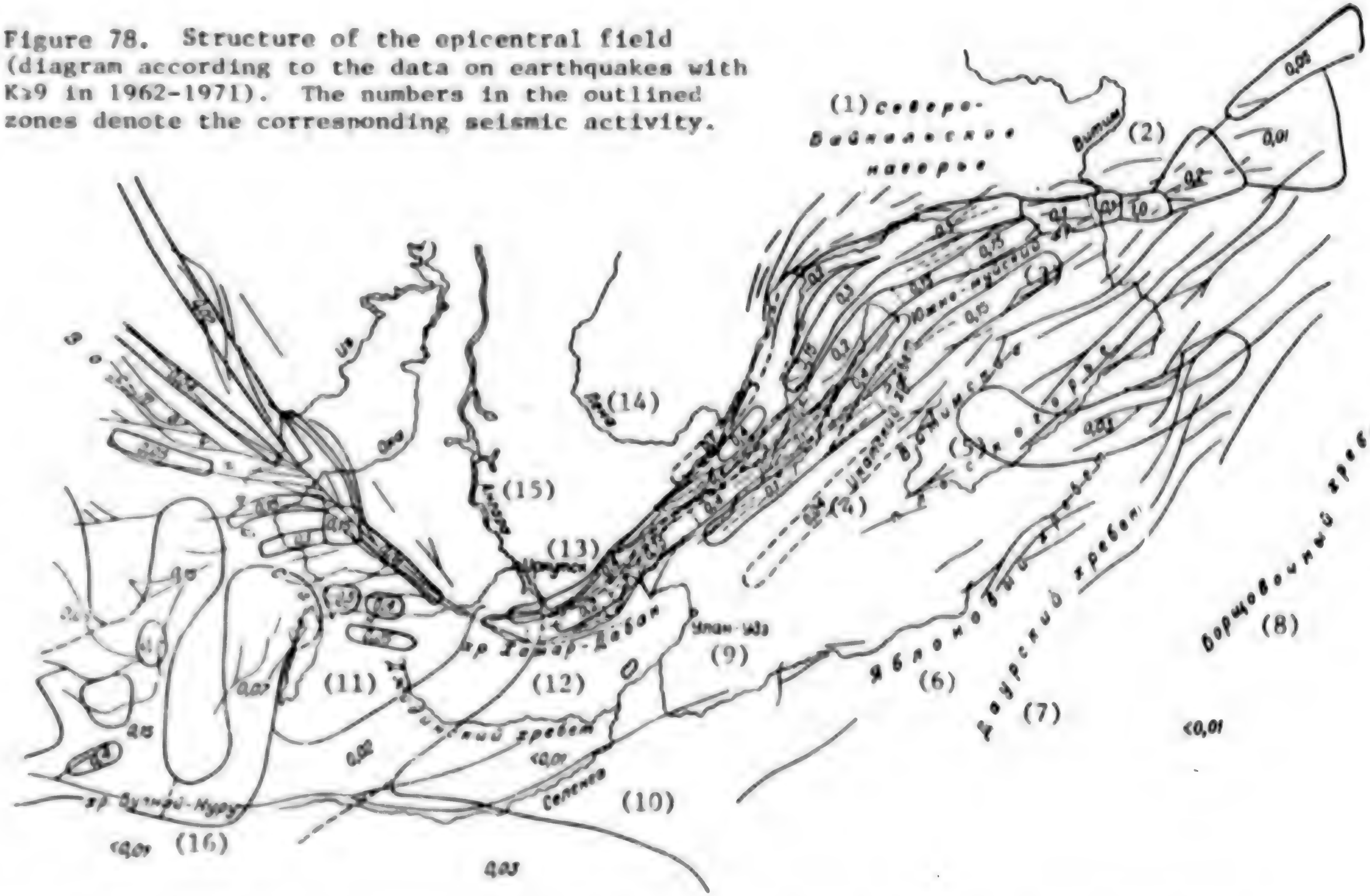
Key:
1. Oka; 2. Uda; 3. Kirenga; 4. Lena; 5. Badaybo; 6. Chara; 7. Udokan ridge; 8. Kodar ridge; 9. Muya ridge; 10. Nelyat'; 11. Yankan ridge; 12. Sredniy Kalar; 13. Olekma Stanovik; 14. Olekma; 15. Vitim; 16. Vitim plateau; 17. Ulan-Burgasy ridge; 18. Bodon; 19. Barguzinskiy ridge; 20. Chakit; 21. Muyakanskiy ridge; 22. Nizhneangarsk; 23. Kumora; 24. Baykal ridge; 25. Tyrgansk; 26. Irkutsk; 27. Kabansk; 28, Ulan-Uda; 29. Malkhanskiy ridge; 30. Kyakhta; 31. Orkhon; 32. Selenga; 33. Zakatensk; 34. Khamar-Daban ridge; 35. Mondy; 36. Kitoyskoye gol'tsy; 37. Orlik; 38. Khapcheranga; 39. Khaylar; 40. Argun'; 41. Shilka; 42. Ingoda; Borshchovochnyy ridge.

Figure 77. Map of the seismic activity for 1962-1971. Computer calculations performed by G. L. Myl'nikova.



Key: 1. Argun'; 2. Khapcheranga; 3. Cherskiy ridge; 4. Shilka; 5. Malkhanskiy ridge; 6. Yablonovyy ridge; 7. Chita; 8. Vitim plateau; 9. Olekma Stanovik; 10. Olekma; 11. Tulik; 12. Vitim; 13. Srednik Kalar; 14. Udokan ridge; 15. Chara; 16. Kodar ridge; 17. Muya ridge; 18. Bodaybo; 19. Vitim; 20. Lena; 21. Chara; 22. Chakit; 23. Kumora; 24. Nizhneangarsk; 25. Barguzinskiy ridge; 26. Baymalskiy ridge; 27. Kirenga; 28. Kabansk; 29. Ulan-Uda; 30. Khamar-Daban ridge; 31. Kyakhta; 32. Selenga; 33. Orkhon; 34. Zakatensk; 35. Irkut; 36. Arshan; 37. Kitoyskiy peaks; 38. Orlik; 39. Tyrgan; 40. Irkutsk; 41. Angara

Figure 78. Structure of the epicentral field (diagram according to the data on earthquakes with K≥9 in 1962-1971). The numbers in the outlined zones denote the corresponding seismic activity.



Key: 1. Northern Baykal Island; 2. Vitim; 3. Southern Muya ridge; 4. Ikatskiy ridge; 5. Vitim plateau; 6. Yablonovyy ridge; 7. Daurskiy ridge; 8. Borshchovochnyy ridge; 9. Ulan-Uda; 10. Selenga; 11. Dzhidinskiy ridge; 12. Khamar-Daban ridge; 13. Irkutsk; 14. Lena; 15. Angara; 16. Bulnay Nuru

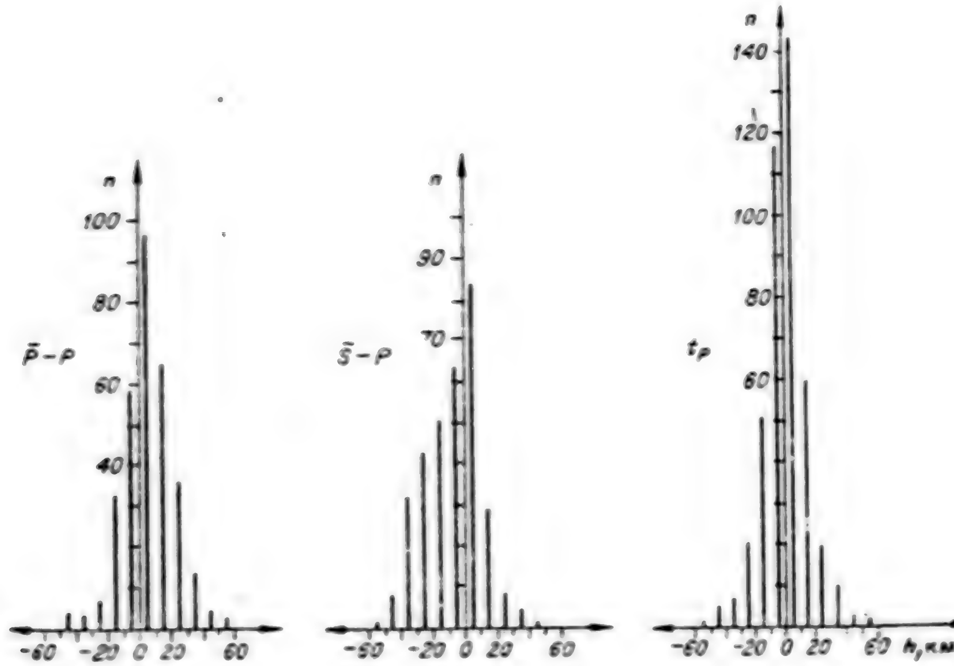


Figure 79. Earthquake distribution in Pribaykal'ye according to center depths h using the differences in times of arrival of the $\bar{P}$ and $(\bar{S})$ waves and the head waves P and absolute travel times of the head waves P (t_P) at individual stations, n is the number of cases.

4. The calculations of the depths of the centers of the earthquakes (along with the establishment of their epicenters) by the observations of the direct waves in the presence of a seismic station at a short epicentral distance (≤10 km). A similar rare possibility occurred, for example, when studying the aftershocks of the Ust'-Muya earthquake of 1968. The calculations performed on the computer on the basis of minimizing the sums of the squares of the errors in the travel times led to the inclusion of shallow depths -- more 0.5 km than 6-10 km.

The distribution of the shocks of the Ust'-Muya earthquake of 1968 with respect to depth is presented below:

Depth of center h, km	Waves used $\bar{S}$	$\bar{P}$
0	5	12
5	2	3
10	4	1
15	0	0

5. The establishment of the total statistical distribution of the depths of the centers of the entire Baykal zone by the observations of the direct waves at the seismic stations with epicentral distances to 50 km (for the defined, fixed positions of the epicenter and values of the center time) from the center-epicenter-station right triangle.

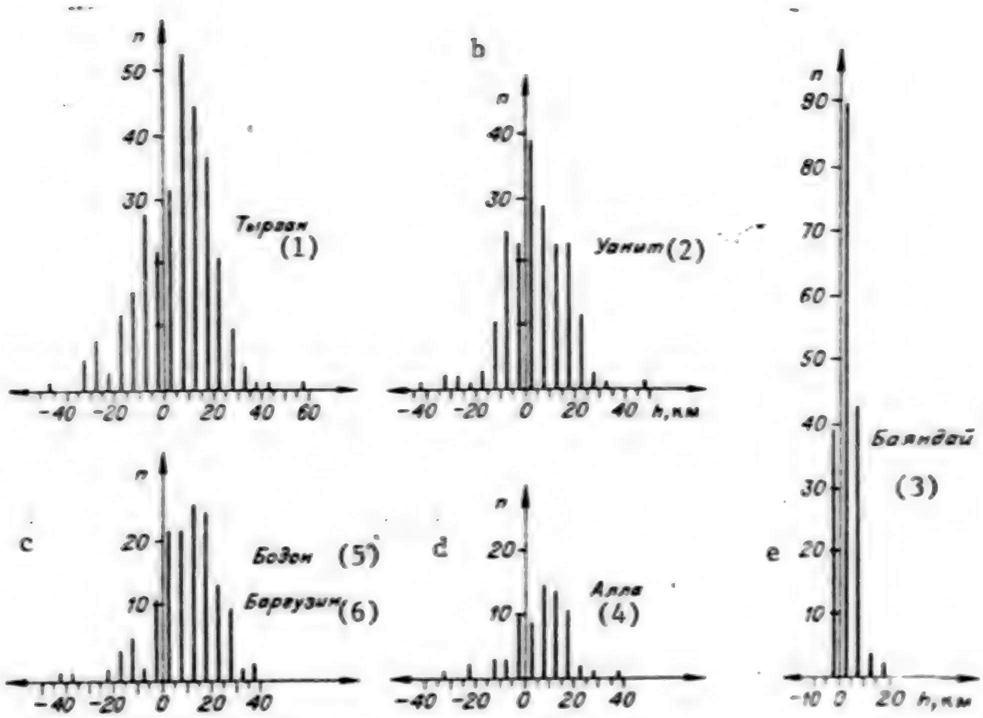


Figure 80. Earthquake distribution with respect to depths.
a-d -- by the observations of the longitudinal head waves P,
e -- by reflected transverse waves

Key:

1. Tyrgan; 2. Uakit; 3. Bayanday; 4. Alla; 5. Bodon; 6. Barguzin

As an example of the distribution we can use the histogram constructed by 952 depth determinations for 1967 (Fig 81). The histograms for the other time periods differ somewhat with respect to external appearance; however, for all of them a large number of cases of determining the imaginary depth of the center and wide range of variation of it are characteristic. This is natural if the actual depths are shallow (a few kilometers), and the accuracy of the individual determinations is low, which actually occurred.

6. Use of macroseismic data for strongest earthquakes.

An estimate of the center depths was made for the ten strongest earthquakes of Pribaykal'ye by the previously constructed isoseismal maps. The calculations were performed on the basis of the known macroseismic formulas (N. V. Shebalin, 1968) using the numerical parameters both specially determined for Pribaykal'ye and averaged over the various seismically active regions. According to these calculations, the centers of the quite strong earthquakes can also be located at shallow depths (to 10-15 km), but as a result of low reliability of determinations only auxiliary significance can be attached to them. The only result in this case indicates significant depths, but they do not find confirmation from any other seismologic observations.

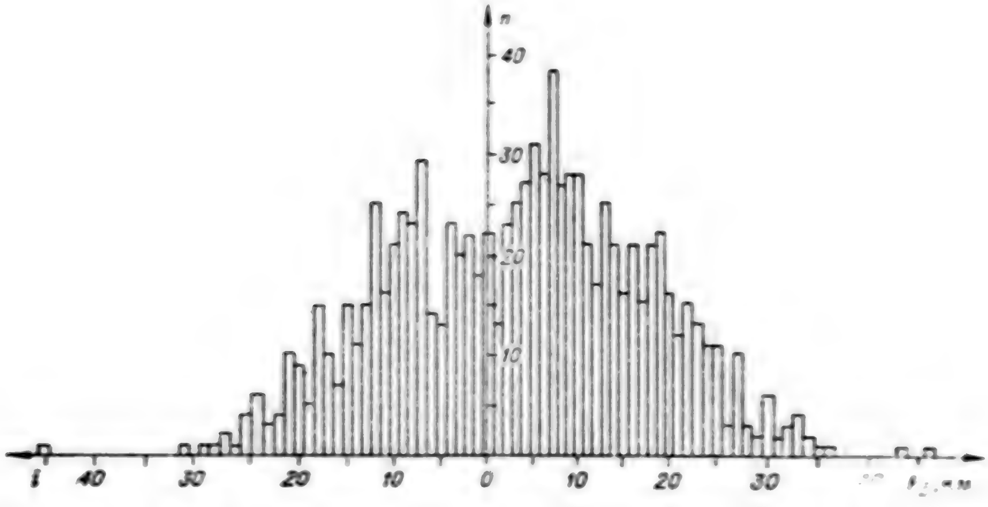


Figure 81. The distribution of the depths of centers of Pribaykal'ye earthquakes in 1967 in accordance with the observations of the $\bar{S}$ waves (n is the number of determinations)

Summing up everything that has been said above, it must be recognized that on the modern level of understanding of earthquakes in Pribaykal'ye, the depths of the centers of the majority of them (weak, constantly recorded earthquakes) can be considered to be shallow, that is to say, provisionally equal to ~5 km. The correctness of this assumption is confirmed, in particular, by the fact that at this depth of center, the estimates of the crust thickness made by the observations of the reflected waves during the earthquakes agree in a number of areas of Pribaykal'ye with the data obtained by deep seismic soundings. The conclusion of the shallow depths of the centers also agrees with the results of the modern studies of the seismicity of other rift zones, for example, the East African rift in Kenya (Molnar, Agaewae, 1971), the Central Atlantic, in Iceland (Ward, et al., 1969).

This, of course, does not mean that there can be no smaller number of earthquakes with deeper centers in Pribaykal'ye. It is possible, for example, that the Kodar earthquakes of 1970 were somewhat deeper. On the whole, in solving the problems of estimating the depths of the centers it is necessary to find additional paths, in particular, obviously it is necessary to consider the possibilities of the discovery of the type pP (sS) waves at small epicentral distances.

Recurrence Rate of the Pribaykal'ye Earthquakes

The average recurrence rates of the earthquakes of different force is one of the most important characteristics of the seismic condition. It is of interest to study the average recurrence rate of the earthquakes both in all of Pribaykal'ye and in individual sections of it isolated with respect to seismic or other signs. For this purpose, a number of linear recurrence rate graphs were calculated by the earthquake catalog data for Pribaykal'ye

in recent years (the logarithm of the number of earthquakes of the corresponding energy as a function of the logarithm of the energy). The results of the calculations performed by the least squares method are presented in Table 13. Fig 82 shows the areas for which the calculations were made. The energy classes of the earthquakes K in all cases were determined using the known T. G. Rautian nomogram by the observations of the seismic station network for Pribaykal'ye.

The most important parameter of the recurrence rate graph -- its angular coefficient γ -- for large areas (all of Pribaykal'ye, the rift region) is determined quite stably, and its numerical value (-0.5) turns out to be close to the average for the other regions. Moreover, for individual parts of the regions the values of the angular coefficients differ noticeably, indicating the known nonuniformity of the seismic process. This begins to be shown already on comparison of the two arbitrarily selected halves of the rift region: northeastern and southwestern, the boundary between which passes along the meridian between the Svyatoy Nos Peninsula and the Barguzinskiy ridge and along the parallel north of the Ushkan'i Islands. However, here the difference is within the limits of possible error: the angular coefficient is higher in the northeastern than in the southwestern part of the rift zone. Making the transition to smaller regions, entirely defined differences are detected. Thus, in the vicinity of the Selenga River delta and the adjacent parts of Baykal, the angular coefficient is reduce (~-0.4).

Obviously, the angular coefficient of the recurrence rate graph in the vicinity of the Tunkinskiy basins and the southeastern part of Eastern Sayan is low. This lowness, however, is less defined, for when calculating the angular coefficients for the last 5 years (1967-1971) it is true that by a smaller number of observations it was not a low value that was obtained but a high one (~-0.62, ordinate for K=10 equal to 0.3). However, this recurrence rate graph does not agree with the facts known for this region inasmuch as then it would be necessary to expect repetitions of earthquakes of the 14th energy class every 100 years, the 16th class every 1500 years, and so on. According to the actual data, earthquakes of ~16th class occurred in the region in the 19th century and in the middle of the 20th century. The recurrence rate graph with smaller angle of inclination (see Table 13) agrees better with these facts. The high values for the coefficients were obtained for the local region in the central part of the Ikatskiy ridge (the long-lasting Ikatskiy earthquake swarm).

It is interesting that for the series of aftershocks of the Mogodskaya 1967, Tas-Yuryakh 1967 and Kodar 1970 earthquakes the angular coefficient of the recurrence rate graph has an entirely normal value close to the mean for the zone. The results for the earthquake swarm on the northern part of the Barguzinskiy ridge (the end of 1966 to the beginning of 1967) are scattered. In this case the very low value of the angular coefficient is determined, [illegible] it is necessary to note that this conclusion is obtained by the [illegible] number of observations and its insufficiently high objectivity is not excluded.

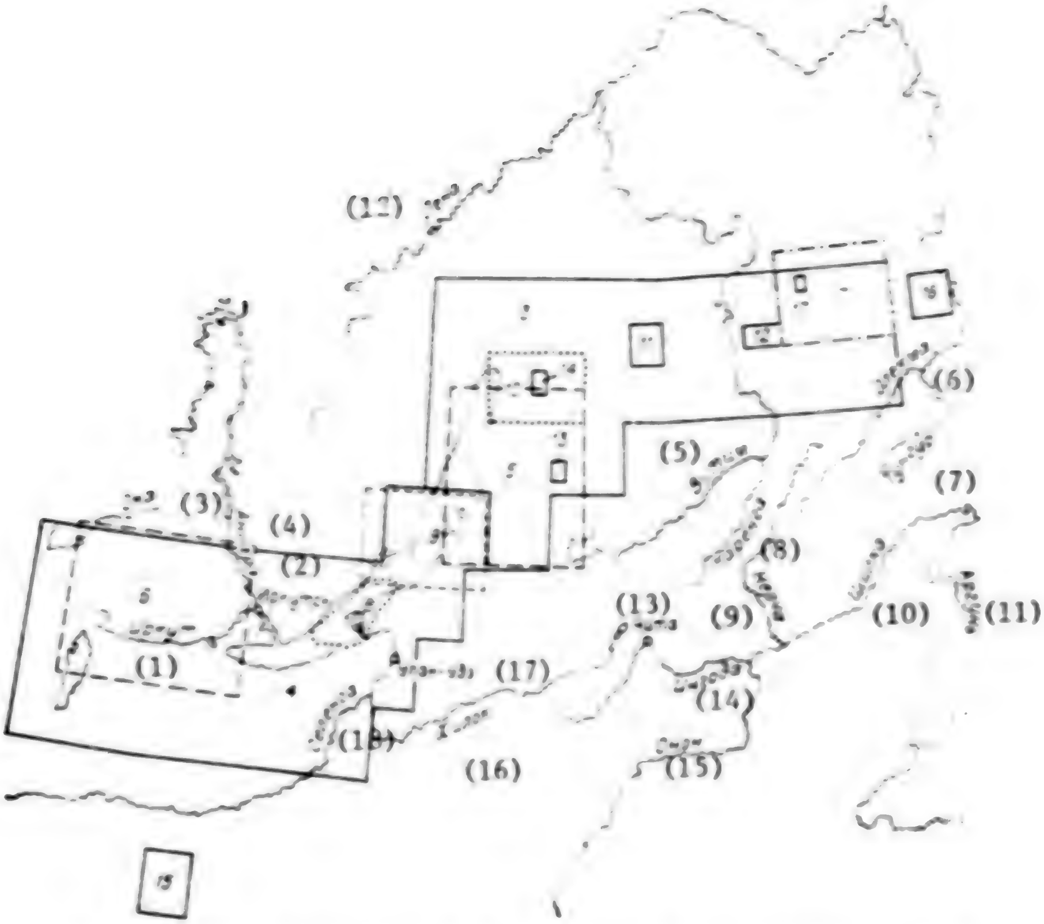


Figure 82. Schematic of the regions of calculation of the earthquake recurrence rate graphs. The numbers correspond to the numbers of the regions in Table 13.

Key:

1. Irkut; 2. Irkutsk; 3. Oka; 4. Angara; 5. Vitim; 6. Olekma; 7. Tungur; 8. Karenga; 9. Nercha; 10. Shilka; 11. Argun'; 12. Lena; 13. Chita; 14. Ingoda; 15. Onon; 16. Khilok: 17. Ulan-Ude; 18. Selenga

It is known that the difference in angular coefficients of the recurrence rate graphs can be connected with a difference in properties of the destroyed medium.

On destruction of less uniform, fractured material, higher values of this coefficient are detected. Possibly, the medium in the vicinity of the Selenga River delta, in the region of the Upper Muya-Muyakan basins and to some degree in Central Baykal and obviously in the Tunkinskiy basins, is characterized by somewhat different distinguishing properties by comparison, for example, with the vicinity of the Barguzinskaya basin and the Barguzinskiy ridge. Let us note that in all of the enumerated regions with low value of the angular coefficient of the recurrence rate

graph already during the historic period, strong earthquakes occurred, but together with them the number of aftershocks after the significant shock was often very great. This problem, however, is not simple, for the dependence of γ also on the deformation rate is possible (with an increase in rate the value of γ decreases).

The results of the calculations by the recurrence rate graphs obtained for the mean intervals between the earthquakes of the highest classes (see Table 13) can of course have only approximate significance inasmuch as they were obtained with significant extrapolation of the supposedly linear function and under the condition that the seismic process is stable, that is, it is correctly described by the observations in recent years. However, comparison of them with the historic information (the last decades and 100 to 200 years) on the strong earthquakes of Pribaykal'ye not used in the calculations indicates that they do not contradict these data. Another reason in favor of the possibility of such approximate estimates is the fact of satisfactory agreement with the recurrence rate graph constructed for the rift zone by the instrument information (Fig 83), the data on the paleoseismodislocations obtained for systematic seismogeological studies in this region.

The summary of the paleoseismodislocations gives the following distribution of their number:

Force	12	11-12	11	10-11	10	9-10	9	8-9
No of earthquakes	2	1	3	1	41	8	17	1

The indicated data referred to a significantly longer time. It is of course impossible exactly to establish the time interval which these data represent. Beginning with the seismogeological signs, it is possible to estimate it approximately at a thousand years.

Obviously, the earthquakes of 16th class (force 9) for this time period turn out to be already nonrepresetative: information about them is incomplete. The initial data are plotted on the graph (see Fig 83) also under the assumption that the encompassed time period is twice as great (equal to 2000 years), which is not excluded. Here, somewhat better agreement with the continuation of the recurrence rate of the graph is detected. On the whole, it is necessary to recognize that the number of known paleoseismodislocations agrees entirely satisfactorily with the calculated recurrence rate graph for the data of this type. A similar picture is also observed in the case where the investigation was performed not for the entire zone but for the northeastern and southwestern halves of it separately.

Table 13

Recurrence Rate of Pribaykal'ye Earthquakes

(a) № района	(b) Район	(c) Границы района (d) с. ш., град.	(e) в. д., град.	(f) Площадь, тыс. км²	(g) Период, год	(h) Классы K	(i) Число землетрясений	(j) Угловой коэффициент γ	(k) Ордината при K = 10	(l) Средняя повторяемость землетрясений (лет) K = 14	K = 15	K = 16	K = 17
1	Вся зона	48–60	96–122	~ 1½ m11	1965–1971	9–14	2005	−0,49 ± 0,03	1,78 ± 0,06	1–2	5	15	50
2	Зона рифта (3+3)	Согласно рис. 82		437	1968–1971	8–12	3071	−0,52 ± 0,01	1,68 ± 0,01	2	10	30	90
3	северо-восточная часть	»	»	212	1968–1971	8–12	2076	−0,55 ± 0,01	1,47 ± 0,01	5	20	70	240
4	юго-западная часть	»	»	225	1968–1971	8–12	995	−0,48 ± 0,02	1,26 ± 0,03	5	15	40	120
5	Баргузинский	53,0–55,5	108,5–112,0	64	1962–1971	8–12	1376	−0,54 ± 0,02	0,91 ± 0,03	5*	20*	60*	190*
6	Тункинско-саянский	51–53	100–104	61	1962–1971	8–11	294	−0,43 ± 0,02	0,41 ± 0,02	20	60	200	750
7	Кодаро-Удоканский	56,0–57,3	117,0–120,0	26	1965–1971	7–10	1194	−0,50 ± 0,01	0,58 ± 0,03	20	50	150	400
8	Дельта р. Селенги	Согласно рис. 82		14½	1962–1971	8–12	429	−0,41 ± 0,01	0,59 ± 0,02	25	80	250	850
9	Средний Байкал	52,7–54,0	106,5–109,5	29	1965–1971	8–11	618	−0,40 ± 0,03	0,92 ± 0,03	10	30	70	200
9	»	52,7–54,0	106,5–109,5	29	1965–1971	8–12	623	−0,46 ± 0,04	0,86 ± 0,06	5	10	30	80
10	Северный Байкал	55,0–56,0	109,5–112,0	17½	1965–1971	8–11	579	−0,49 ± 0,02	0,77 ± 0,02	10	30	80	250
10	То же без Баргузинского роя 1966–1967 гг.	55,0–56,0	109,5–112,0	17	1965–1971	8–11	497	−0,52 ± 0,02	0,66 ± 0,02	15	50	150	450
11	Верхнемуйский — Муяканский	55,8–56,4	113,3–114,2	3,7	1965–1971	7–10	961	−0,41 ± 0,03	0,71 ± 0,06	25	90	300	950
12	Муйский	56,0–56,3	116,1–117,0	1,9	1967–1971	7–11	396	−0,55 ± 0,02	0,10 ± 0,04	10	20	50	150
13	Икатский	54,20–54,45	111,1–111,5	0,7	1962–1971	8–11	404	−0,62 ± 0,02	0,25 ± 0,02	~100	450	1600	5500
14	Баргузинский рой 1966–1967 гг.	55,41–55,77	110,62–110,98	0,9	1966–1967	7–11	184	−0,36 ± 0,02	0,05 ± 0,04	170	700	3000	12000
15	Афтершоки Могодского землетрясения	47,9–48,8	102,5–103,5	7½	1968–1972	9–11	139	−0,48 ± 0,06	0,81 ± 0,05	10	40	100	350
16	Афтершоки Тас-Юряхского землетрясения	56,2–56,8	120,5–121,5	4,1	1968–1972	8–11	253	−0,52 ± 0,00	0,53 ± 0,00	35	100	400	1300
17	Афтершоки Кодарского землетрясения	56,8 ± 0,1	117,7 ± 0,1	0,2	1970	7–10	309	−0,52 ± 0,06					

[See key on p 241]

[Key to Table 13, p 240]:

a. No of the region
b. Region
c. Boundary of the region
d. north latitude, degrees
e. east longitude, degrees
f. Area, thousands of km^2
g. Period, years
h. Classes, k
i. No of earthquakes
j. Triangular coefficient γ
k. Ordinate for K=10
l. Mean recurrence rate of the earthquakes (years)

1. Entire zone
2. Rift zone (3+3) According to Fig 82
3. Northeastern part
4. Southwestern part
5. Barguzinskiy
6. Tunkinsko-sayanskiy
7. Kodaro-Udokanskiy
8. Selenga River delta According to Fig 82
9. Central Baykal
10. Northern Baykal
10. The same without the Barguzinskiy swarm of 1966-1967
11. Upper Muya-Muyakan
12. Muya
13. Ikatskiy
14. Barguzin swarm of 1966-1967
15. Aftershocks of the Mogodskiy earthquake
16. Aftershocks of the Tas-Yuryakh earthquake
17. Aftershocks of the Kodar earthquake

Note. The estimates marked by an asterisk were obtained on variation of the angular coefficient and the ordinate of the recurrence rate graph by the amounts of the mean square errors.

It is possible to arrive at the same conclusion if we are oriented toward the total number of strong shocks beginning with a defined class. Thus, according to the recurrence rate graph normalized with respect to time, the total number of shocks in the class interval of K_1-K_2(K_2>K_1) is defined by the ratio

$$N = a\,\frac{10^{\gamma(K_1-K_0)} - 10^{\gamma(K_2-K_0+1)}}{1-10^{\gamma}}\cdot T,$$

where K_0 is the class of the earthquakes by which the activity (10th) is determined; T is the time period for which the total number of shocks is found; γ is the angular coefficient of the recurrence rate graph taken from Table 13; a is the number of shocks determined by the ordinate of the recurrence rate graph for K_0=10 (also from Table 13).

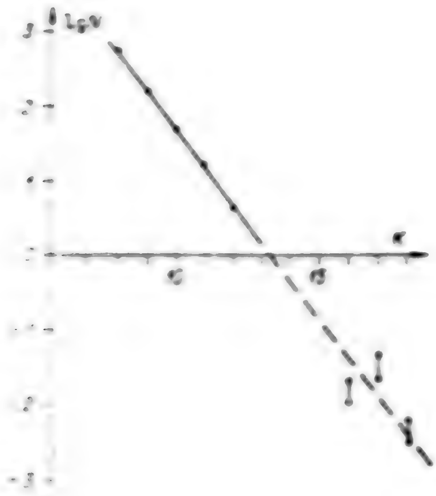


Figure 83. Graph of the recurrence rate of earthquakes in the Baykal rift zone (the dark circles are according to the instrument data, and the light circles, according to the data on the paleoseismodislocations).

Considering all of the earthquakes of force 10 or higher, in the formula we set K_1=17, K_2=18, γ=-0.52, a=48 (antilog 1.68), T=1000 and we obtain

$$N = 48\,\frac{10^{-0.52(17-10)} - 10^{-0.52(18-10)}}{1-10^{-0.52}}\cdot 1000 = 33,$$

that is, in a thousand-year period, according to the recurrence rate graph, about 33 such earthquakes should occur. This agrees well with the data presented on p 290 (about 50 earthquakes) because the interval of 1000 years is taken quite provisionally.

In addition, the used parameters of the recurrence rate graph are subject to random errors.

If, for example, γ is equal not to -0.52, but -0.50, then for the calculation in place of 33 earthquakes we obtain 43.

Thus, for approximate estimates obviously it is entirely possible to use the linear recurrence rate graph constructed by the instrument data, extrapolating it to the region of the shocks of higher energy classes.

The earthquakes of the highest force (18th energy class) can be expected in Pribaykal'ye (an area of ~1.5 million km^2) with a frequency of one and a half centuries, earthquakes of 17th class (force 10 in the epicentral region) occur on the average once every century and a half, 16th class, after ~15 years (see Table 13). If we consider only the region of the Baykal rift (a smaller area), then these time intervals are approximately doubled. It is necessary to expect earthquakes individually in the northeastern and southwestern parts of this zone still more rarely (let us

note that the difference in the numbers presented in the table with respect to the corresponding classes in the given case is within the limits of the possible errors of the estimates).

The earthquakes of the 16th class in one of the most seismically active regions of Pribaykal'ye -- in the vicinity of the Selenga River delta -- must be observed every three-quarters of the century, 17th class every 200 years. Similar but somewhat smaller time intervals were obtained for another especially active region -- the Upper Muya basin and the Muyakan ridge.

With respect to two versions of the solution presented in Table 13 for the regions of Central and Northern Baykal, it is indicated to what degree the estimates obtained depend on the used initial data.

The at first glance extraordinary results were obtained for the Muya region where in 1957 one of the strongest earthquakes of Pribaykal'ye occurred, classified as class 17. The region is characterized by high seismic activity A_{10}, the epicenters are concentrated in a small area making up part of the sublatitudinal seismic belt. To the south and north of it they are in practice absent. However, in spite of their high seismic activity A_{10}, the mean time intervals between high energy earthquakes obtained as a result of extrapolation are very large. The data in Table 13 indicate that in the Muya earthquake of 1957 a rare phenomenon for this small area was realized.

The significance of the mean time intervals between possible strong earthquakes can be determined by considering the unique sequence of earthquakes for Pribaykal'ye in the highly localized region of the central part of the Ikatskiy ridge.

Finally, obviously analogous calculations for the aftershock zones of two other strong earthquakes -- Mogodskiy and Tas-Yuryakh -- also lead to the same conclusion. Of course, the calculations with respect to the series of aftershocks damping in time cannot determine the mean time intervals between the strong earthquakes, but they indicate that even for such significant intensifications of the seismic process as the sequences of aftershocks which according to the available data are not characteristic for the ordinary conditions in Pribaykal'ye the recorded weak shocks are still insufficient for the strong earthquakes to be repeated frequently enough in small areas. Thus, in order that the earthquakes of the 16th energy class in the indicated Muya region repeat every 100 years on the average under steady state conditions, the observed seismic activity would have to be at least 10 times higher than the modern value.

Of course, what has been stated does not exclude the practical possibility of the repetition in individual cases of several strong earthquakes in a small area over a short time interval (as, for example, occurred in the vicinity of the Tas-Yuryakh earthquake), but this must be classified as fluctuations in the process in spite of the mean characteristics.

There are no convincing proofs of nonstationarity of the seismic process in Pribaykal'ye at the present time, and there are no sufficient grounds for considering it stationary. The time period of the seismic observations is too short for such conclusions. The facts referred to here are investigated below.

Development of the Seismic Process in the Vicinity of the Baykal Rift

As is known from studies of the mechanisms of the earthquake centers (see Chapter V), the stress orientation in the earth's crust over the broad territory of Pribaykal'ye is characterized by a high degree of constancy. The overwhelming majority of the epicenters of the earthquakes undoubtedly are closely connected with the relatively narrow and long belt of the intracontinental Baykal rift which is a quite unique seismogenic structure. It is not excluded that the tectonic developments of the Baykal rift under a relatively stable and uniform field of stresses active in the earth's crust can follow some general laws. Inasmuch as the existence of the rift structures is exhibited, in particular, in the sequence of earthquakes, it is possible to expect some regularity also in the time-space distribution of them.

One of the principal problems of studying the development of the seismic process in time is investigation of the problem of the possible cyclicity of the earthquakes. Unfortunately, the studies in this direction encounter great difficulties in connection with the fact that the observation periods (the periods for which there is information about the earthquakes) do not encompass the time intervals during which it is possible to observe the recurrence of the process in its basic features.

Nevertheless, sometimes this type of analyis is possible, and it leads to interesting results. Thus, S. A. Fedotov (1968) advanced the ideas of a seismic cycle of 140 ± 60 years for the earthquakes of Kamchatka, the Kurili Islands and Northeastern Japan.

In order to study the development of the seismic process in the vicinity of the Baykal rift, a diagram of the time-space distribution of the earthquakes was constructed. The time is plotted on the y-axis, and the x-axis was used as the provisional axial line of the rift system oriented as shown in Fig 84 by the dotted line. The epicenters from the adjacent regions of the epicentral field were projected on this line. The territory in which the epicenters of the investigated earthquakes were located is overlaid by a degree grid in Fig 84.

First the degrees of longitude between the 99th to the 105th meridians (along the 51.5° north latitude parallel) were used as the scale with respect to the horizontal axis, and then the provisional scale obtained on intersection of the indicated axial line of the rift system by the diagonals joining the opposite corners of the degree grid and, finally, the degrees of longitude between the 114th to 120th meridians (along the 56th parallel). The near geographic regions are indicated on the axis.

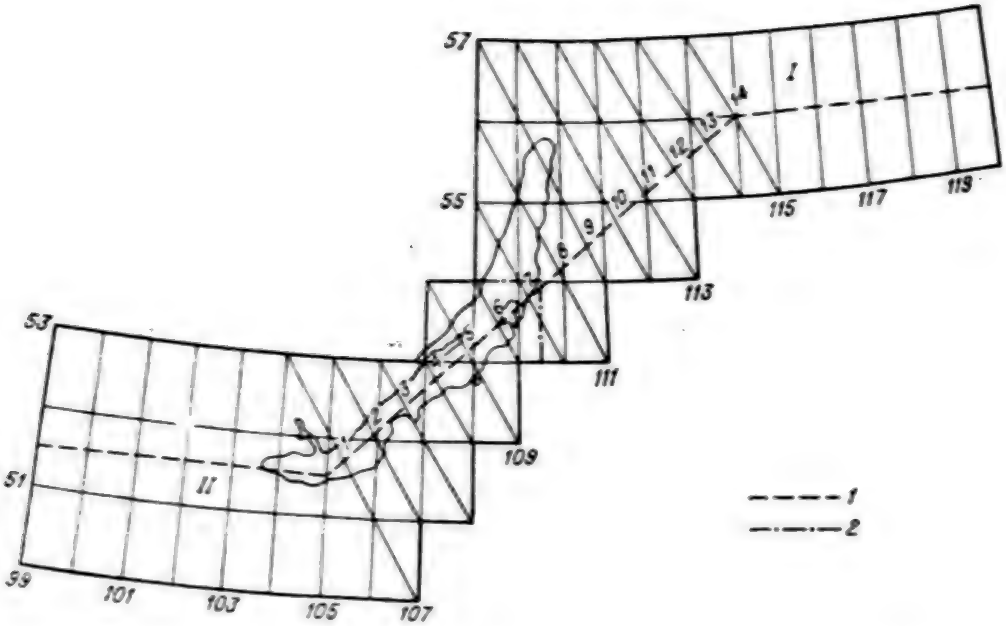
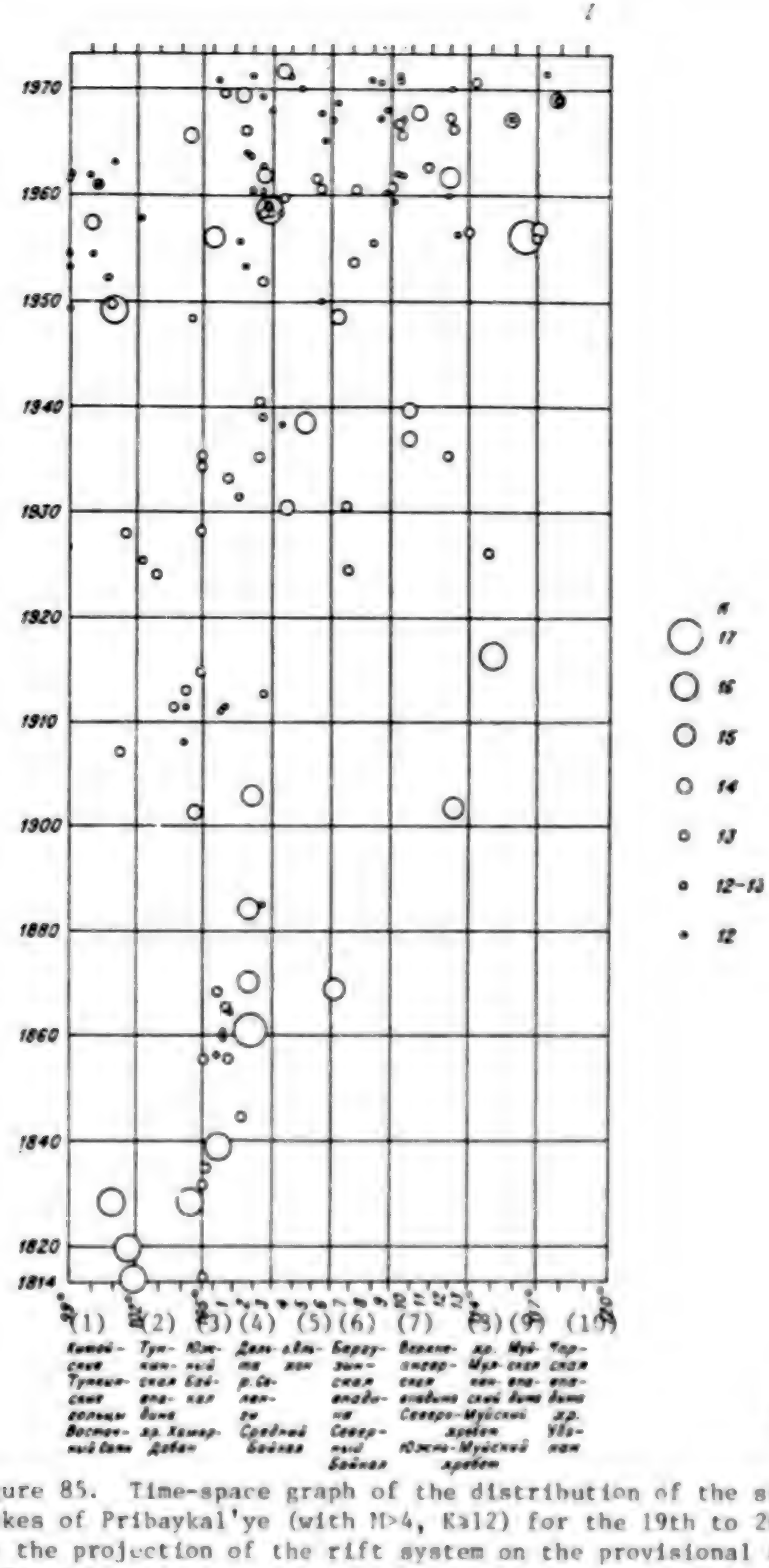


Figure 84. Schematic of the provisional axis of the Baykal rift zone.
1 -- provisional axis of the rift zone; 2 -- provisional boundary separating the northeastern (I) and southwestern (II) parts of the zone.

The diagram was constructed in two versions: 1) with respect to all known earthquakes with M=4 or more (energy class 12 and higher) for the entire time period for which there are historical and instrument data (see Fig 85); 2) from 1967 to 1972 by the earthquakes with energy class 9 (in order to involve information about weaker shocks; Fig 86). The source of the initial material was the catalog of earthquakes by which the map of the epicenters of the strongest earthquakes of Pribaykal'ye and the list of instrumentally determined epicenters for recent years were constructed.

The used initial data for the development of the time periods are non-equivalent with respect to completeness and accuracy. For the 19th century there are only scattered data on the strongest earthquakes, and then only in the southwestern half of the rift zone. Undoubtedly, it is for this reason that the righthand side of the time-space graph (see Fig 85) remains unfilled in for the indicated time period.

There are somewhat more detailed data for 1902-1914 in connection with organization in Pribaykal'ye of the first instrument observations and also for the time period from the middle of the 1920's to the beginning of the 1940's, but they pertain predominantly also to the southwestern part of the zone and to a high degree are based on the materials of only one seismic station "Irkutsk."



[See key on p 247]

Figure 85. Time-space graph of the distribution of the strongest earthquakes of Pribaykal'ye (with M>4, K≥12) for the 19th to 20th centuries (in the projection of the rift system on the provisional axis according to Fig 84).

[Key to Fig 85, p 246]:

1. Kitoyskiya
   Tunkinskiy peaks
   Eastern Sayan

2. Tunkinskaya basin
   Khamar-Daban ridge

3. Southern Baykal

4. Selenga River delta
   Central Baykal

5. Ol'khon Island

6. Barguzinskaya basin
   Northern Baykal

7. Upper Angara basin
   Northern Muya ridge
   Southern Muya ridge

8. Muyakanskiy [Muyakan] ridge

9. Muyskaya [Muya] basin

10. Charskaya [Chara] basin
    Udokan ridge

There are no data for the World War I period, the revolution or World War II.

The following period encompasses the 1950's where in Southern Pribaykal'ye the three relatively low-sensitive seismic stations functioned which were unable to make any complete recording of the earthquakes from the northeastern parts of the rift zone.

Finally, since 1960-1961 the seismicity of the rift system has been studied by a network of 10 to 20 seismic stations making it possible to record earthquakes from all parts with more or less identical detail. This is clearly noticeable in Fig 85 where the variety of all other of the above-described recording conditions is definitely exhibited. Of course, more numerous data correspond to the better conditions. Thus, in accordance with Fig 85 it is impossible to confirm any special general intensification of seismic activity in the recent decades.

As a result of studying the time-space distribution of the earthquakes it is possible to draw the following conclusions.

The strong earthquakes (Mondy in 1950 and Central Baykal in 1959) noted in recent times in the southwestern and central parts of the zone occurred in the regions where previously -- a century ago -- a strong earthquake also occurred: correspondingly in the vicinity of the Tunkinskiye basins and in the Proval Bay. However, the locations of these epicenters do not mutually coincide (the centers were located at an in different local seismogenic structures). Therefore there are not sufficient data to conclude cyclicity of seismic process in Pribaykal'ye. For other regions of Pribaykal'ye where strong earthquakes also occurred in the last decade there is no historical data.

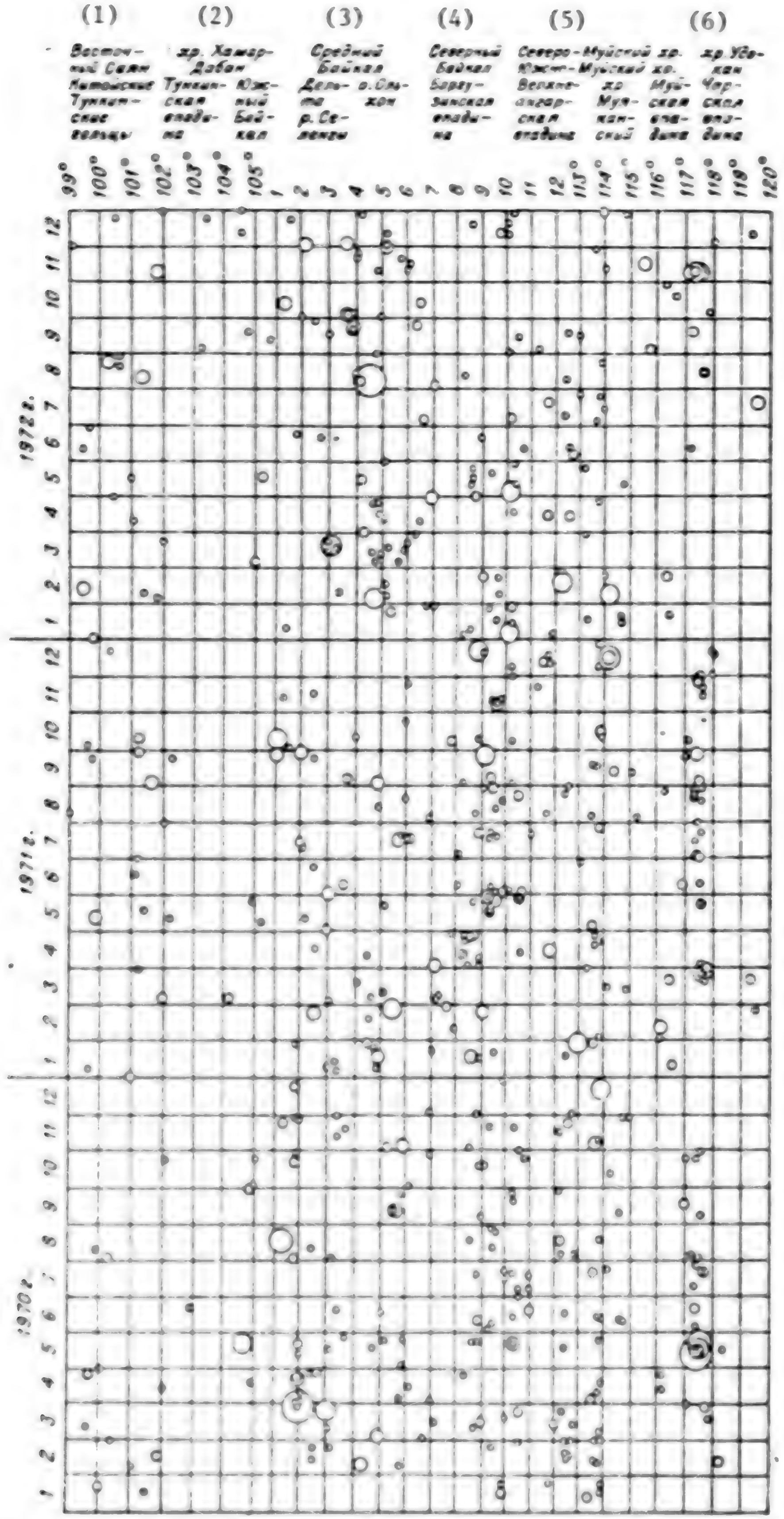
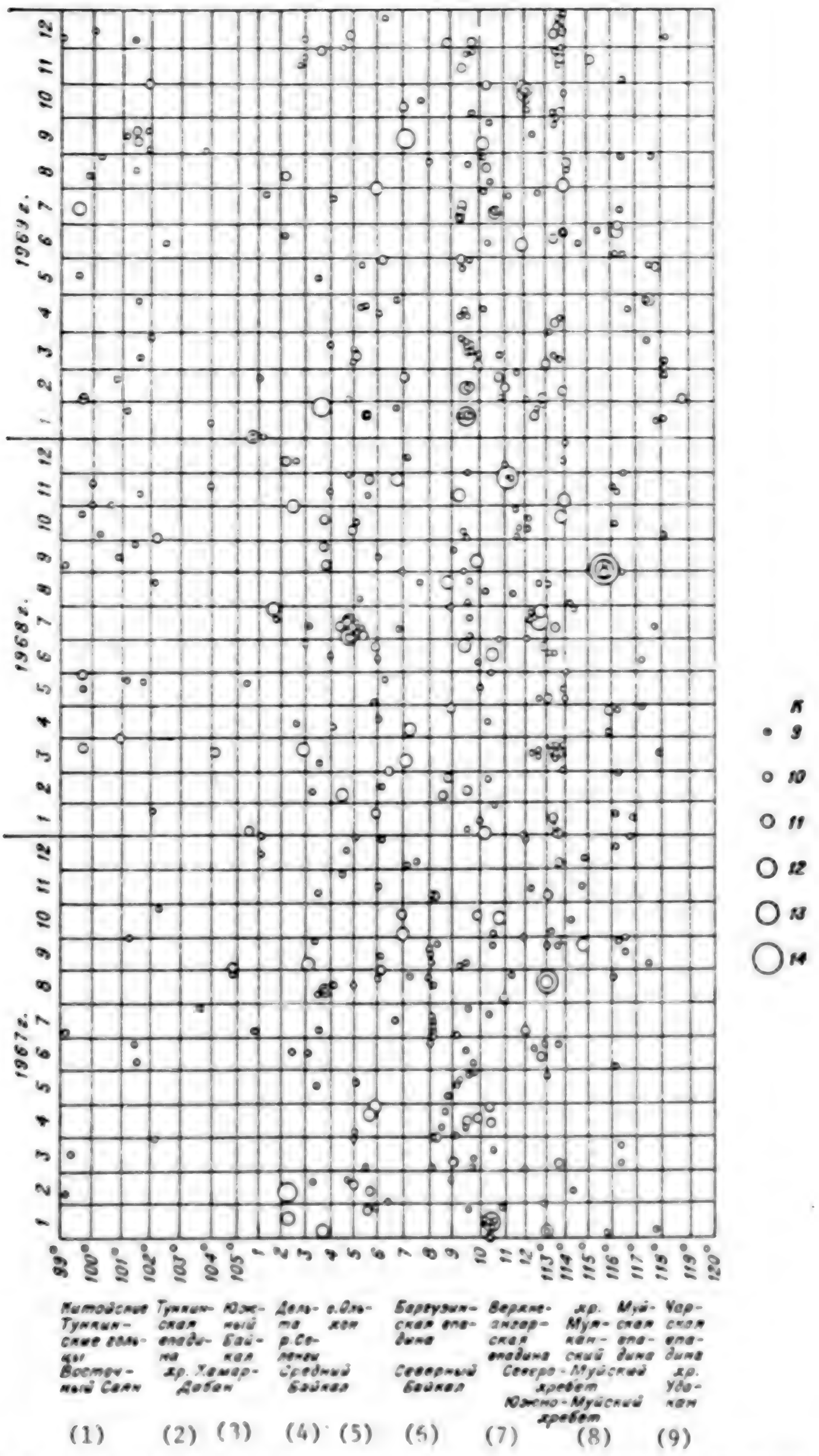


Figure 86. Time-space graph of the earthquake distribution for Pribaykal'ye [See key on p 250]



with K≥9 for 1967-1972 (in the projection on the provisional axis of the rift system according to Fig 84) [See key on p 250]

[Key to Fig 86, p 248]:

1. Eastern Sayan
   Kitoyskiye Tunkinskiy peaks
2. Khamar-Daban ridge
   Tunkinskaya basin
   Southern Baykal
3. Central Baykal
   Selenga River delta
   Ol'khon Island
4. Northern Baykal
   Barguzinskaya basin
5. Northern Muya ridge
   Southern Muya ridge
   Upper Angara basin
   Muyakan ridge
   Muya basin
6. Udokan ridge
   Chara basin

[Key to Fig 86, p 249]:

1. Kitoyskiye
   Tunkinskiye peaks
   Eastern Sayan
2. Tunkinskaya basin
   Khamar-Daban ridge
   Southern Baykal
3. Selenga River delta
4. Central Baykal
5. Ol'khon Island
6. Barguzin basin
   Northern Baykal
7. Upper Angara basin
   Northern Muya ridge
   Southern Muya ridge
8. Muyakan ridge
   Muya basin
9. Chara basin
   Udokan ridge

The available facts indicate that the strong earthquakes occur in sequence which excludes the possibility of talking about any gradual furrowing of the substrate in the rift zone in a defined time interval in one direction. The epicenter of the subsequent strong shock usually is located far from the epicenter of the preceding earthquake (Mondy earthquake of 1950 -- on the southwestern flank of the zone, Muya earthquake of 1957 -- in the northeastern part, the Central Baykal earthquake of 1959 in the central regions). The investigation of the observation materials for individual years indicates that this situation is retained also for the weaker earthquakes (with $K \geq 12$). Under the effect of the powerful stresses, the movements in the earth's crust take place here and there, and the position of the epicenter shifts discontinuously, often from one edge of the zone to another.

The analysis of the time-space distribution of the earthquakes leads to the conclusion that the modern seismicity of the individual parts of the rift system is different. The vicinity of the southwest end of

Lake Baykal and the region adjacent to it on the west and also the central parts of the Kalar ridge to the Udokan ridge is a low-seismic zone. By comparison with the adjacent regions of Northern Baykal and northeast, the weaker earthquakes occur in the vicinity of the Barguzinskaya basin to North Baykal.

The decrease in shocks with K≥12 during the last decades in the Kitoyskiye-Tunkinskiye peaks to Eastern Sayan attracts attention. Such shocks were also not recorded before the Ust'-Muya earthquake (1968) or the Kodar earthquake (1970) of 14th class (during the time period after the Muya earthquake of 1957 on the northeastern flank of the rift system).

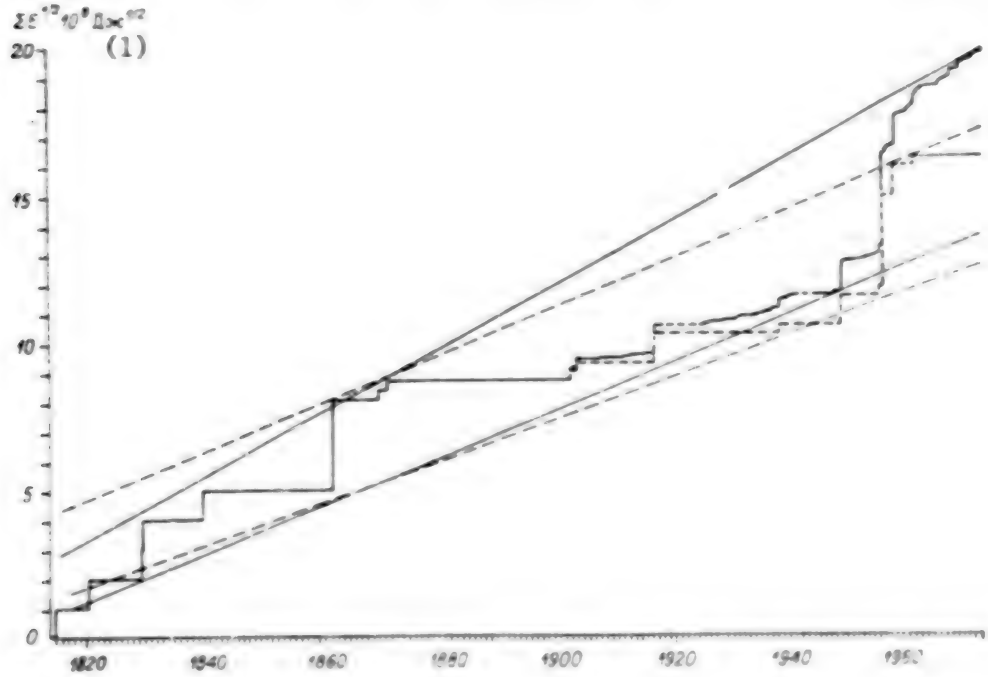


Figure 87. Graph of the release of provisional elastic deformations in the vicinity of the Baykal rift (by the Ben'off procedure)

Key:
1. $joule^{1/2}$

However, if we return to Fig 86 which contains information also about weaker earthquakes, it turns out that in both cases the weaker shocks were nevertheless observed in significant number. The close groups of earthquakes (see Fig 86) correspond to swarms of shocks and sequences of aftershocks, more or less extended belts along the time axis -- activation of seismicity -- often after more significant earthquakes. In other cases, after such earthquakes with respect to released energy, similar activation of seismicity was not observed.

On the whole, when investigating the indicated data, the impression is created that the seismic process in the vicinity of the Baykal rift is quite uniform with, of course, significant time fluctuations of it.

Another characteristic of the development of the seismic process in the Baykal rift region was obtained when studying the release -- in the sequence of earthquakes -- of the provisional elastic deformations (according to Ben'off) (Fig 87). For construction of this figure the same materials were used as for the above-described graph of the time-space distribution of the earthquakes and the map of the strongest earthquakes of Pribaykal'ye (the presented procedure of approximate transition from the macroseismic historical information about the earthquakes to the energy classes is explained above).

The form of this function is the usual, stepped function, and it indicates that the seismic processes over the time period during which there are historical data do not damp. The straight lines bounding the graph (see the solid lines of Fig 87) diverge with time which could indicate an increase in intensity of the seismic process. However, it is more natural to consider that this is caused by nonuniformity of the information used when constructing the graph -- the passage (especially in the 19th century) of not only significant aftershocks after strong earthquakes, but also significant independent shocks. As for the process as a whole, it is possibly more or less stationary.

If beginning in 1900 we construct a graph of the release of elastic deformations, just as for the preceding period, only for the strong shocks (from the 15th class; the broken dotted line in Fig 87), then the dotted straight lines bounding the graph can in practice be considered parallel.

In discussing the individual cases of the process in recent time, it is necessary to note that after a relatively calm period in the 1950's and 1960's a noticeable (it is necessary to think, temporary) activation of seismic activity occurred, and the level of the total provisional deformation approached the upper boundary. Judging by the general nature of the investigated function, a gently sloping section of it should follow this. If this is correct, then in the forthcoming decades the danger of large earthquakes will be reduced, for the energy of the seismic process has temporarily exhausted itself to a significant degree.

The indicated conclusions appear to be still more substantiated if we consider that on the graph (see Fig 87) several strong earthquakes from the extreme northeastern end of the seismic zone are not plotted (Olekma and Nyukzha 1958, Tas-Yuryakh 1967). With the inclusion of these earthquakes the level of late activation would increase still more.

The mean rate of release of provisional elastic deformations (the slope of the strip between the dotted lines in Fig 87) for the regions of the Baykal rift turns out to be comparable with the analogous values for the vicinity of Northern Tyan'-Shan' (Kurochkina, Nersesov, 1970).

CHAPTER IX. SEISMIC VULNERABILITY OF THE BAYKAL REGION

The vulnerability calculations were performed by the known procedure of Yu. V. Riznichenko (Riznichenko, et al., 1969) using the seismic activity maps, the maximum possible earthquakes and the damping law of the quaking with distance. In practice the values of the activity were initially taken from the map (see Fig 76) constructed in accordance with the observations for 1962-1971.

When calculating the seismic vulnerability, high dependence of the results on comparatively small variations of the angular coefficient of the recurrence rate graph γ was discovered. Therefore in the final version of the calculation, the activity map was used which was obtained not for one value of the angular coefficient over the entire zone, but for minimum differentiation of it which better corresponds to the initial material although obviously it does not fully solve the problem. For the northeastern half of the zone, the value of γ was taken as before equal to -0.5, and for the southwest (west of the 109th meridian) -0.4. This map of the seismic activity essentially differed little from the first: the configuration of the isolines was left as before and usually only small shift of them occurred. Considering the possible errors in calculating the vulnerability caused by other reasons and the errors in compiling the activity maps themselves, no great significance should be attached to the indicated small differences in the seismic activity maps.

Damping of Seismic Quaking in the Baykal Region [Pribaykal'ye]

The damping characteristics of the seismic quaking with distance in the case of the strong earthquakes of Pribaykal'ye required to calculate the seismic vulnerability can be obtained when analyzing the isoseismal map for known earthquakes. In this case usually the known macroseismic formula is used (Shebalin, 1968)

$$I_i = bM - s \lg \sqrt{\Delta_i^2 + h^2} + c,$$

where M is the magnitude of the earthquake; h is the depth of the center; Δ_i is the isoseism radius; I_i is the force at a distance of Δ_i from the epicenter, b, s, c are constant parameters. The indicated relation is

satisfied only approximately; therefore it is possible to determine only the approximate values of the parameters. For estimation of them in the given step, the isoseismic maps for eight earthquakes in Pribaykal'ye could be used:

Earthquake	Date	M
Srednebaykal'skoye [Central Baykal]	29 August 1959	6.7
Khamar-Dabanskoye [Khamar-Daban]	8 January 1963	4.5
On Central Baykal	10 February 1963	5.5
Ust'-Muyskoye [Ust'-Muya]	31 August 1968	4.5
Svyatonosskoye [Svyatoy Nos]	24 November 1968	4.8
Verkhneangarskoye [Upper Angara]	26 November 1968	5.3
On Central Baykal	28 March 1970	5.5
Kodarskoye [Kodar]	15 May 1970	5.6

The parameter b which, according to the published data, varies little from region to region was assumed equal to 1.5 -- the mean for a number of seismically active regions. The coefficients s and c were calculated by the least squares method from the expression

$$s\lg\sqrt{\Delta^2 + h^2} - c = bM - I_i.$$

The mean radius of the isoseism Δ_i was found as the square root of the product of the greatest and least radii. The initial data used in the calculations and the results obtained are presented in Table 14.

As the summary results of the estimate of the mean values of the damping coefficients obviously it is necessary to take the following: s=3, c=2-1/2 (for the given value of b=1-1/2).

The calculation of the average diameters of the isoseisms on the basis of the well-presented macroseismic formula using the indicated values of the parameters (Table 15) indicates satisfactory agreement of them with the dimensions of the isoseims established by V. P. Solonenko according to the empirical data.

The calculations of the force at the epicenter for a given magnitude by these formulas also agrees satisfactorily with the empirical relation of V. P. Solonenko between the magnitude and force (described and used earlier).

Table 14

Calculation of the Damping Coefficients

Землетрясение (1)		$1{,}5M - I_i$	$\lg\sqrt{\Delta_i^2 + h^2}$	
			$h=10$ км	$h=20$ км
Среднебайкальское	(2)	2,1	1,316	1,380
		3,1	1,687	1,699
		4,1	2,035	2,037
		5,1	2,510	2,511
		6,1	2,578	2,578
Хамар-Дабанское	(3)	0,75	1,525	1,544
		1,75	1,689	1,699
		2,75	1,984	1,987
На Среднем Байкале	(4)	2,25	[illegible]	1,458
		3,25	1,724	1,732
		4,25	2,188	2,189
Усть-Муйское	(5)	2,1	1,256	1,315
		3,1	1,562	1,578
		4,1	2,016	2,018
		5,1	2,232	2,233
Святоносское	(6)	1,2	1,072	1,188
		2,2	1,624	1,637
		3,2	1,862	1,865
		4,2	1,990	1,992
Верхнеангарское	(7)	2,95	1,831	1,835
		3,95	2,284	2,285
		4,95	2,393	2,394
На Среднем Байкале	(8)	2,25	1,755	1,774
		3,25	1,961	1,969
		4,25	2,159	2,163
Кодарское	(9)	2,4	1,561	1,605
		3,4	1,917	1,926
		4,4	2,186	2,188
Вычисленные значения коэффициентов s и c	(10)		$s=3{,}0\pm0{,}3$; $c=2{,}2\pm0{,}6$;	$s=3{,}1\pm0{,}3$; $c=2{,}5\pm0{,}6$

Key:

1. Earthquake
2. Srednebaykal'skoye [Central Baykal]
3. Khamar-Dabanskoye [Khamar-Daban]
4. On Central Baykal
5. Ust'-Muyskoye [Ust'-Muya]
6. Svyatonosskoye [Svyatoy Nos]
7. Verkhneangarskoye [Upper Angara]
8. On Central Baykal
9. Kodarskoye [Kodar]
10. Calculated values of the coefficients s and c

Let us note that the adopted values of the quaking damping coefficients not only differ from the mean values obtained by the different seismically active regions: b=1.5; s=3.5; c=3 (Shebalin, 1968). It was necessary, however, to consider that the picture of the quake damping for the individual earthquakes can be quite characteristic, noticeably differing from average. The transition from the average characteristics to the more specific (in particular, consideration of the azimuthal peculiarities) requires further special investigation. The values of the coefficients are indeed of more precise determination calling on the additional initial data.

Table 15

Calculated Diameters of the Circular Isoseisms (h=10 km), km

[illegible] (1)	[illegible] (2)				
	10	9	8	7	6
17 th (X)	32	80	173	380	815
16 th (IX)	—	40	80	200	430
15 th(VIII)	—	9	32	104	225

Key:

1. Energy class of the earthquakes, K (force)
2. Force

Map of Maximum Possible Earthquakes in the Baykal Region [Pribaykal'ye]

In calculating the seismic vulnerability, two versions of the map of maximum possible earthquakes were used: the map obtained on the basis of the correlation with the seismic activity A_{10} and the map constructed as a result of seismogeological studies. The latter was borrowed from the paper by V. P. Solonenko "Seismotectonics and the Modern Structural Development of the Baykal Rift Zone" (1968b).

With respect to the first map (Fig 88) it is necessary to make some explanations.

The efforts to establish a correlation specific to Pribaykal'ye (with different averaging areas when establishing the mean activity or in particular, with respect to the areas of the aftershock zones for the earthquakes of the corresponding class) were not crowned with success. Therefore the map was constructed by the correlation of Yu. V. Riznichenko for Central Asia (Riznichenko, 1966):

$$\lg A_{10} = \bar{2}.84 + 0.21(K_{max} - 15),$$

based on a great deal of factual material. The radii R of the areas for which the seismic activity was found in this case are as follows (km):

K	10	11	12	13	14	15	16	17
R	20	20	21	27	34	46	72	144

The previously described maps of the epicenters of the Pribaykal'ye earthquake for 1962-1971 (see Fig 74) and the corresponding seismic activity map (see Fig 76) were used as the source of actual material with respect to the distribution of the epicenters.

As should be expected, the regions of the strongest possible earthquakes on the K_{max} map obtained are basically located in the rift zone. A large area in the central and northeastern parts of the zone is occupied by the regions of possible earthquakes of 16th energy class. The distribution of the epicenters of the known, strongest earthquakes (with $K \geq 14$) also indicated on the map agrees satisfactorily in a number of cases with the picture obtained. However, sometimes the difference is highly significant, and accordingly the map was corrected as follows: in the northeast, in the vicinity of the epicenter of the Muya earthquake of 1957 the calculated value of K_{max} was 16. Inasmuch as the Muya earthquake was stronger, the $K_{max}=17$ region was indicated on the maps (bounded by the dash-dotted line). A value of K_{max} somewhat higher than a calculated one is indicated on the map for the region of Tas-Yuryakh and Nyukzha earthquakes. The analogous situation occurred in the vicinity of the Selenga River delta where, as is known, in 1862 there was a very strong earthquake, and the calculated data hardly reached values of $K_{max}=12$.

The $K_{max}=16$ region approximated in the longitudinal direction is indicated in the vicinity of the Tunkinskiy basins. According to the calculations K_{max} here does not quite reach class 16 (and in a noticeably smaller area).

Significant divergences are detected in the extreme southwestern zone -- in the region of known strongest earthquakes of 1905 in Northern Mongolia. The calculated values of K_{max} do not reach 16, and the shocks of 1905 must be considered 18th class. The correspondence of infinity of the Mogodskoye earthquake of 1967 in the southern boundary of the zone is still worse. If it can be considered to belong to 17th class, and the calculated value K_{max} will turn out to be equal to 13. Another earthquake in Northern Mongolia 6 February 1957 was 15th class and turned out to be in the region with $K_{max}=12$.

In the corresponding regions on the K_{max} map changes have been introduced. Here the areas for the possible earthquakes of higher classes were selected in accordance with the Utsu and Seki ratio (Utsu, Seki, 1955) derived by them for the aftershock zones:

$$\lg s = 1.02\ M - 4.01,$$

where s is the area of the zone, M is the magnitude of the earthquake.

The ratio of the longitudinal and transverse axes of these regions bounded on the map by the dash-dot lines was taken equal to 1:2; they were oriented according to the general strike of the structures.

The dotted lines on the map outline the regions in which the calculated values of K_{max} do not reach the corresponding (indicated at the given point) maximum values only by 0.25 or even less. This is the region in northern and eastern Pribaykal'ye and also in the western part of the seismic zone (a meridionally oriented area).

The described map, K_{max} unconditionally cannot claim to complete our final solution of the problem of maximum possible earthquakes in Pribaykal'ye. This is all only a working version designed only for approximate calculations. As new data are accumulated, it must be supplemented and modified. For greater substantiation of the conclusions in the calculations presupposing the use of the information about K_{max}, other versions must be considered.

The map obtained is similar only in general features to the previously mentioned map of maximum possible earthquakes with respect to the seismogeological data. The map based on the results of the seismogeological studies was detailed; in many cases relatively narrow strips were isolated on it where according to the used criteria the earthquakes of higher intensity are possible, in particular, even in the regions with low modern seismic activity. On the map constructed by the seismological data, in these areas it is not necessary to expect strong earthquakes (for example, between the southwestern extremity of Baykal and the Tunkinskaya basin). At the same time, certain areas on this map where there are no strong earthquakes according to the results of the seismogeological studies are encompassed only by a region of high values of K_{max}. As an example we can use the regions adjacent to Northern Baykal on the east, north of the Barguzin basin. In general, the regions of high values of K_{max} are broader on this map.

Results of Calculating the Seismic Vulnerability

The elementary areas of ΔS into which the entire investigated territory is subdivided were assumed equal to 0.2° with respect to latitude and 0.2° with respect to longitude in the calculations. Considering the class distribution of K_{max} on the maps of maximum possible earthquakes, the value of $K_{max}+0.5$ is substituted in place of K_{max} for calculating the seismic vulnerability. For calculations of the seismic vulnerability B with force I and higher in practice the value of I-0.5 was taken in the formula.

The angular coefficient of the recurrence rate graph (-0.5) was initially considered constant for the entire zone just as the coefficients in the force damping formula with distance.

When using the K_{max} map constructed by the seismological data, the average recurrence periods of the quakes for earthquakes of force≥9, ≥8, ≥7 (version 1) were calculated. Since the K_{max} map based on the seismotectonic data of the region was compiled for smaller areas, the analogous calculations when using it could be performed only for the earthquakes of force≥9 and ≥8 (version 2). The general concept of the calculated versions of the vulnerability maps can be gotten from Table 16.

All versions of the maps are characterized by certain general features. Thus, in each of them the greatest vulnerability is characteristic of the same regions: Central Baykal, Tunkinskiye basins, Upper Muya-Muyakan basins, the regions between the northeast and the Southern Muya ridge and the Udokan ridge and also the Udokan ridge itself.

The seismic vulnerability of Transbaykal is such that it can be neglected.

The smaller the force for which the vulnerability is calculated, the broader the areas encompassed by the isolines. The vulnerability maps constructed using the K_{max} map based on the seismotectonic signs contain more details than the analogous vulnerability map, on the calculation of which less detailed maps of K_{max} according to the seismological data were used. In the first case in part of the regions the calculations lead to lower values of the vulnerability (as, for example, in the individual sections in the Bayguzinskiy Rayon), and in other areas the regions of calculated vulnerability are somewhat expanded (Southern Baykal, the eastern part of Tunkinskiy basins). However, good correspondence of the maps compiled in these two versions is maintained in general features, and this must be especially emphasized. On the whole the result depends quite little on which of the K_{max} maps was used.

Table 16

Calculated Minimum Mean Repetition Periods of the Quakes (T, Corresponding to the First Isolines), Years

(1) Район	(2) Вариант 1, γ=−0,5			Вариант 2, γ=−0,5		Вариант 1, γ=−0,[illegible]−0,5		
	≥9	≥8	≥7	≥9	≥8	≥9	≥8	≥7
	балл (9)							
(3) Средний Байкал	1000	200	50	1000	200	200	50	20
(4) Тункинские впадины	2000	500	50	2000	500	1000	200	50
(5) Верхнемуйская — Муякан-ская впадины	1000	200	50	2000	200	1000	200	50
(6) Между Южно-Муйским хребтом и хр. Удокан	1000	200	50	2000	500	1000	200	50
(7) Баргузинский	2000	500	100	2000 и больше (8)	500	2000	500	100

Key: 1. Region; 2. version; 3. Central Baykal; 4. Tunkinskiy basin; 5. Upper Muya-Muyakan basin; 6. between the Southern Muya ridge and the Udokan ridge; 7. Barguzinskiy; 8. and more ; 9. force

Note. The K_{max} maps were used in the versions as follows: 1 -- with respect to seismological data; 2 -- with respect to seismotectonic data.

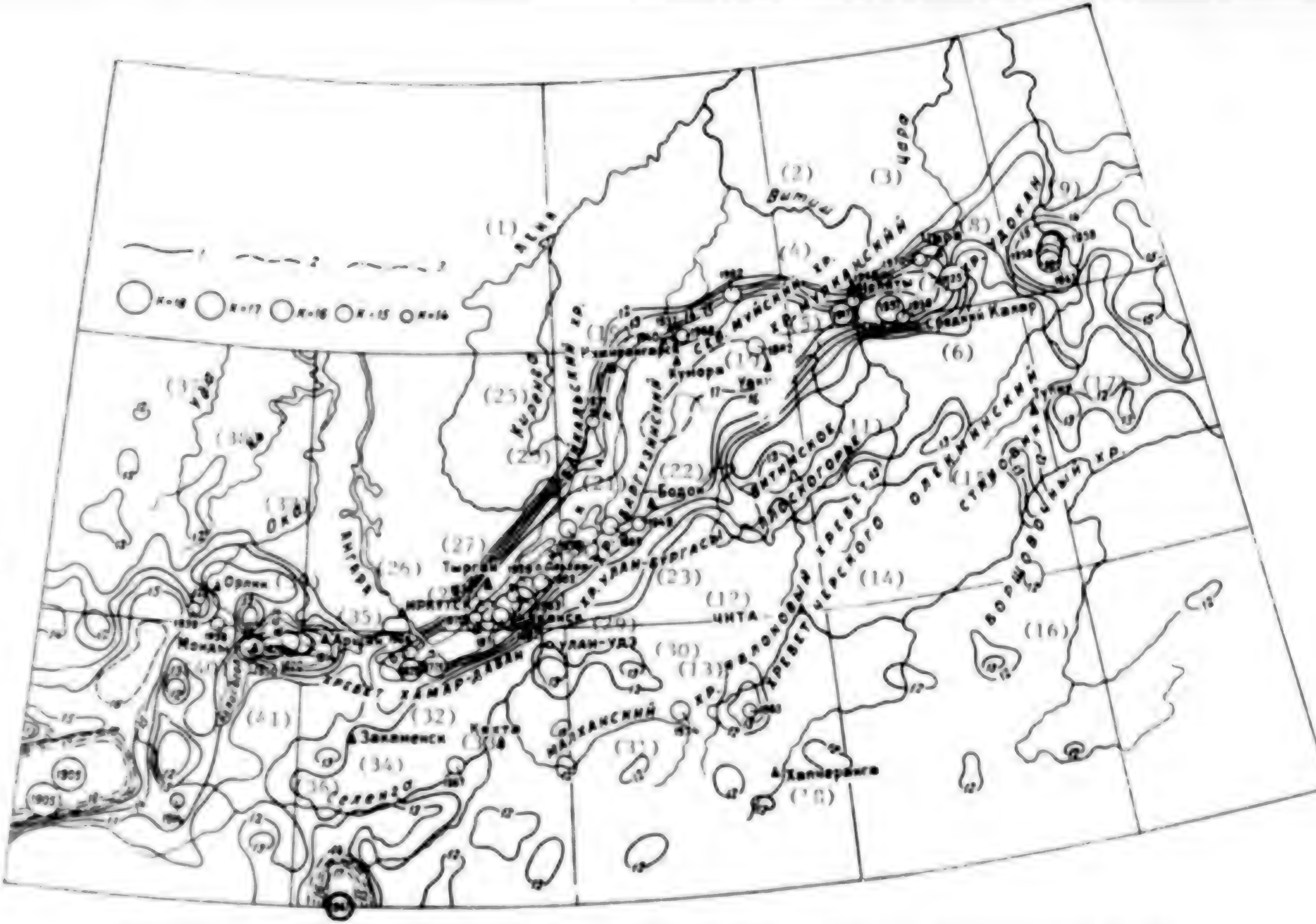


Figure 88. Map of maximum possible earthquakes in Pribaykal'ye (constructed by the Yu. V. Riznichenko procedure)

1 -- isoline K_{max}; 2 -- the same when K_{max} is rounded to large values with exaggeration by ≤0.25; 3 -- corrected by the data on the strong earthquakes.

[See key on p 261]

[Key to Fig 88, p 260]:

1. Lena; 2. Vitim; 3. Chara; 4. Northern Muya ridge; 5. Muyakan ridge; 6. Central Kalar; 7. Nelyaty; 8. Chara; 9. Udokan ridge; 10. Kutora; 11. Vitim plateau; 12. Chita; 13. Yablonovyk ridge; 14. Chersk ridge; 15. Olekma Stanovik; 16. Borshchovochnyy ridge; 17. Tulike; 18. Khapcheranga; 19. Nizhneangarsk; 20. Baykal'skaya ridge; 21. Barguzinskiy ridge; 22. Bodon; 23. Ulan-Burgasy ridge; 24. Ol'khon; 25. Kirenga; 26. Angara; 27. Tyrgan; 28. Irkutsk; 29. Kabansk; 30. Ulan-Ude; 31. Malkhanskiy; 32. Khamar-Daban ridge; 33. Kyakhta; 34. Zakatensk; 35. Arshan; 36. Selenga; 37. Uda; 38. Nya; 39. Oka; 40. Orlik; 41. Mondy; 42. Kosogol Lake.

All the calculated maps satisfactorily characterize the relative distribution of the seismic vulnerability with respect to area, that is, they give objective material for comparing the vulnerability of individual regions with each other. As for its absolute values, it is possible to note the following here.

The maps obtained with the use of the mean angular coefficient of the recurrence rate graphs of the entire zones (-0.5) obviously contain a low estimate of the seismic vulnerability at least for the southwestern half of the rift zone. The strongest seismic regions in this part of the ridge system (Central Baykal, Tunkinskiy basin) making the basic contribution of factual material and of greatest interest when calculating the seismic vulnerability are characterized by a smaller angular coefficient (~-0.4). At the same time in the northeastern half of the zone there are more regions approaching -0.5 with respect to value of the angular coefficient. Therefore when calculating the seismic vulnerability maps in another version (Fig 89-92) it was proposed provisionally to a known degree that the angular coefficient of the recurrence rate graphs is -0.4 for the southwestern part of the rift zone (before the 109° east longitude meridian) and -0.5 for the second half of it.

The comparison of the various versions of the calculations is presented in Table 16 where for the above-noted seismically dangerous regions of the Baykal rift, the values of the time corresponding to the first isoline are given (bounding the territory with the greatest quake repetition rate for the given region).

A comparison of the calculations with the known historic information (Table 17) was made at two points -- Kabansk and Irkutsk for which this information is the most numerous. With respect to individual cases, the conclusions of the recurrence rate of the quakes as a result of the possibility of significant fluctuations are, of course, risky to draw.

In the last two columns of Table 17 we have the results of calculating the seismic vulnerability T_{calc} for the two above-described cases: for γ=-0.4 and γ=-0.4 to 0.5. The first columns contain the data for calculating T_{obs}.

In the time interval for which it is possible to propose the absence of admissible omissions of information, the number of observed earthquakes N of force 5 or more, force 6 or more, and so on is calculated. The average observed time period (T_{obs}) was found by dividing the corresponding time interval by the number of earthquakes. Obviously this value cannot be established very precisely inasmuch as the number of sufficiently strong earthquakes is small, and the known indeterminacy is characteristic of the estimates of the force in the given populated place. Nevertheless, some conclusions can still be drawn.

Table 17

Comparison of T_{obs} and T_{calc} of the Mean Recurrence Periods of the Quakes with Intensity I or more

Балль-ность	Интервал времени, лет	Число землетрясений	$T_{набл}$, лет	$T_{расч}$, лет	
				$\gamma=-0,4-0,5$	$\gamma=-0,5$
		Кабанск			
5	70(1902–1972)	13	5	2*	5
6	70	6	12	15	30
7	70	1–2		25	100
8	~110	1		100	400
9				500	2500
		Иркутск			
5	70(1902–1972)	18	4	7*	25*
6	70	4	20	40	150
7				350	2000
8				>50000	∞

Key:
1. Force
2. Time interval, years
3. No of earthquakes
4. T_{obs}, years
5. T_{calc}, years
6. Kabansk
7. Irkutsk

Note. The asterisk denotes the values for the earthquakes with force 5.

As follows from Table 17, the seismic vulnerability calculated for a value of $\gamma=-0.4$ for the southwestern half of the rift region (and $\gamma=-0.5$ in its northeastern part) agrees more with the facts than the calculations performed for $\gamma=-0.5$ for the entire zone.

With respect to the calculations of T_{calc} for the earthquakes with force 5 (the asterisk in Table 17) it must be noted that the results must be to some degree high, that is, the actual values of T_{calc} can be somewhat lower. This is connected with the fact that in order to calculate the weak earthquakes it is necessary to encompass larger areas of the calculations for which the activity and K_{max} maps should exist. Inasmuch as there are no such maps for large areas, it is necessary to perform the calculations for smaller territories, obtaining a somewhat high estimate of T_{calc}.

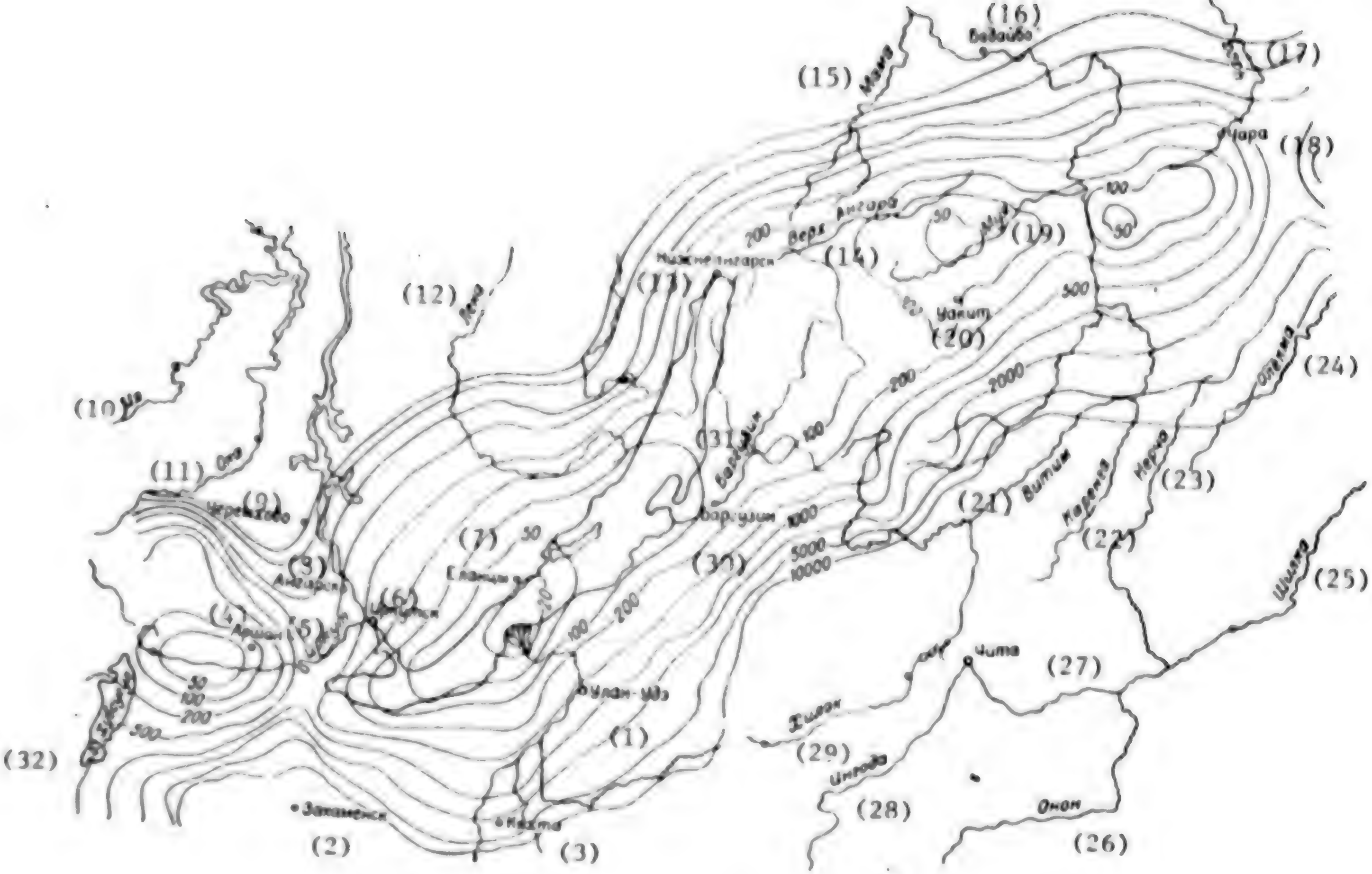


Figure 89. Map of the seismic vulnerability of Pribaykal'ye.
(I≥7, version 1)

Key: 1. Ulan-Ude; 2. Zakatensk; 3. Kyakhta; 4. Arshan; 5. Irkut; 6. Irkutsk; 7. Yelantsy; 8. Angarsk; 9. Cheremkhovo; 10. Iya; 11. Oka; 12. Lena; 13. Nizhneangarsk; 14. Verkh. Angara; 15. Mama; 16. Bodaybo; 17. Chara; 18. Chara; 19. Muya; 20. Yakut; 21. Vitim; 22. Karenga; 23. Nercha; 24. Olekma; 25. Shilka; 26. Onon; 27. Chita; 28. Ingoda; 29. Khilok; 30. Barguzin; 31. Barguzin; 32. Lake Khubsugul

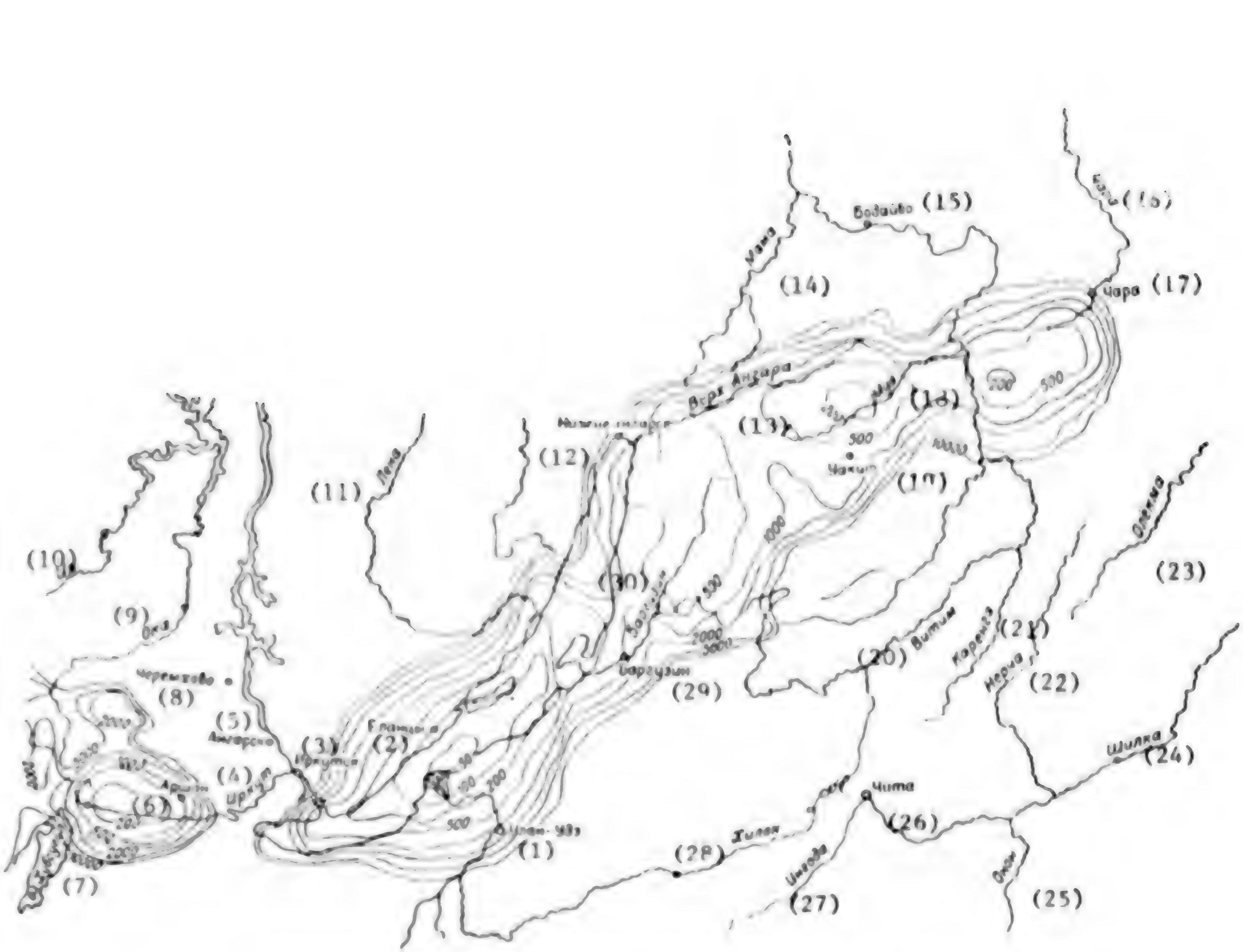


Figure 90. Map of Seismic Vulnerability of Pribaykal'ye
(I≥8, version 1)

Key:

1. Ulan-Ude; 2. Yelantsy; 3. Irkutsk; 4. Irkut; 5. Angarsk; 6. Arshan; 7. Lake Khubsugul; 8. Cheretkhovo; 9. Oka; 10. Iya; 11. Lena; 12. Nizhneangarsk; 13. Verkh. Angara; 14. Mama; 15. Bodaybo; 16. Chara; 17. Chara; 18. Muya; 19. Yakut; 20. Vitim; 21. Karenga; 22. Nercha; 23. Olekma; 24. Shilka; 25. Onon; 26. Chita; 27. Ingoda; 28. Khilok; 29. Barguzin; 30. Barguzin

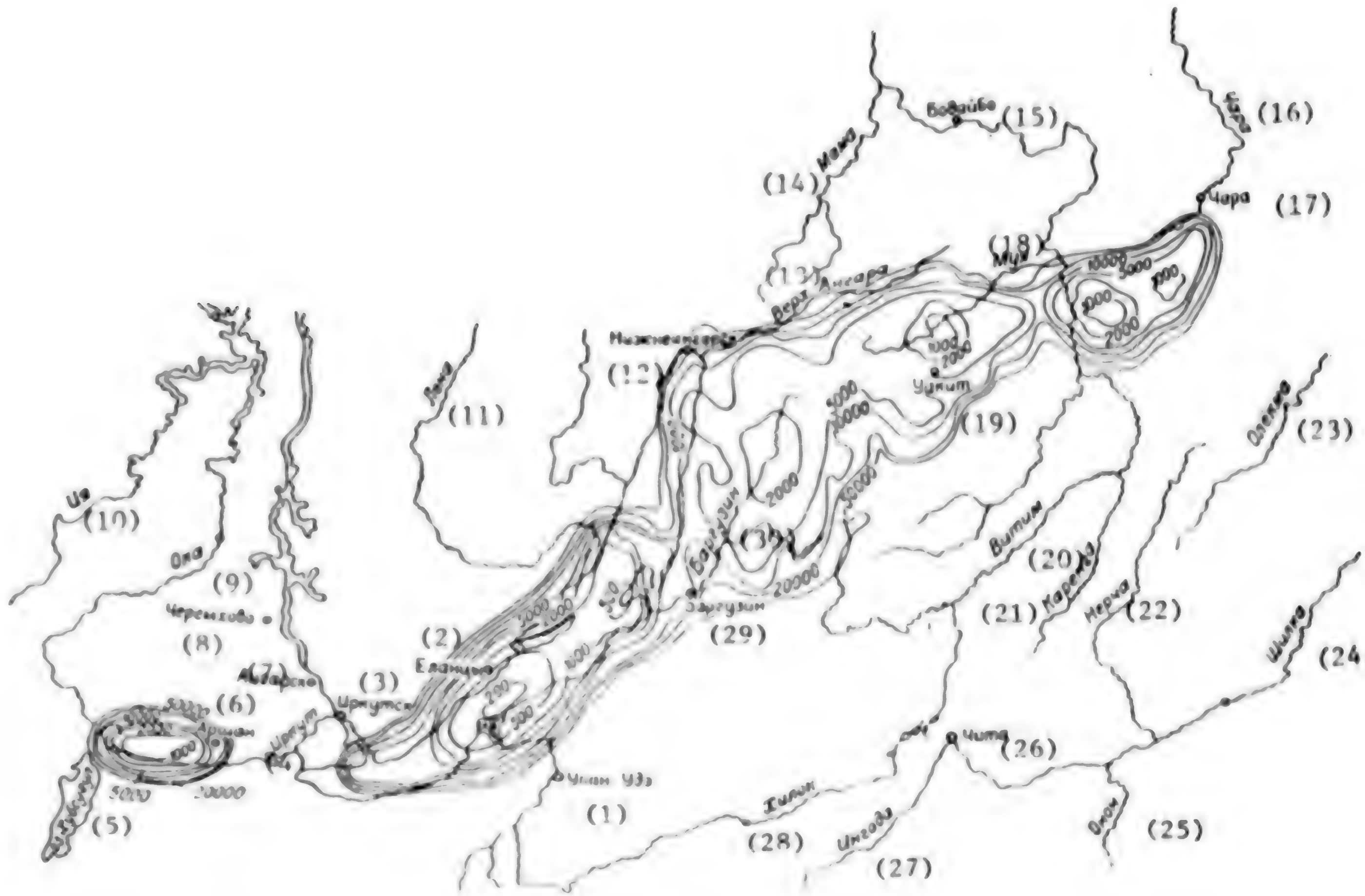
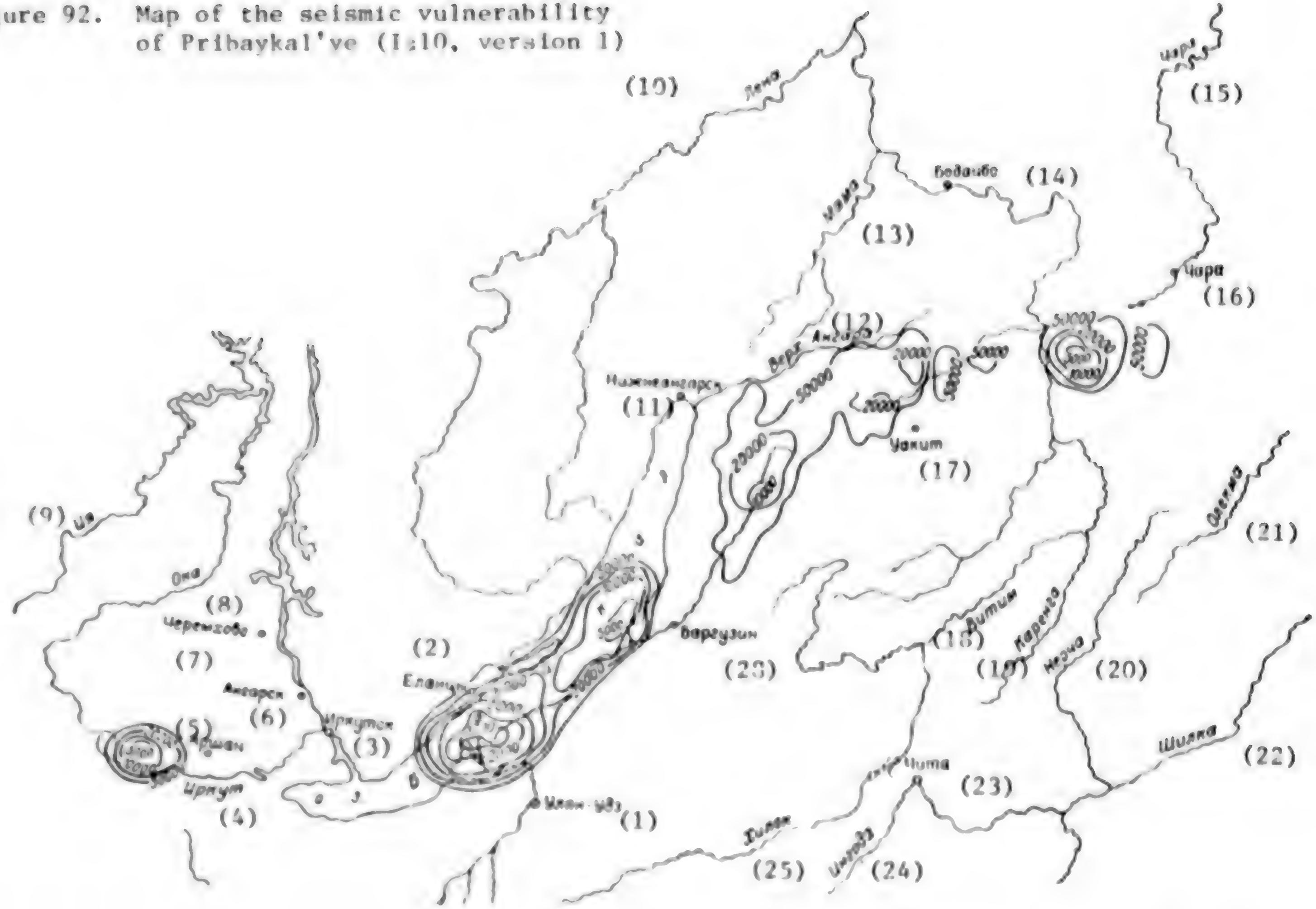


Figure 91. Map of the seismic vulnerability of Pribaykal'ye (I≥9, version 1)

Key:

1. Ulan-Ude; 2. Yelantsy; 3. Irkutsk; 4. Irkut; 5. Lake Khubsugul; 6. Arshan; 7. Angarsk; 8. Cheretkhovo; 9. Oka; 10. Iya; 11. Lena; 12. Nizhneangarsk; 13. Upper Angara; 14. Mama; 15. Boyaybo; 16. Chara; 17. Chara; 18. Muya; 19. Yakut; 20. Vitim; 21. Karenga; 22. Nercha; 23. Olekma; 24. Shilka; 25. Onon; 26. Chita; 27. Ingoda; 28. Khilok; 29. Barguzin; 30. Barguzin

Figure 92. Map of the seismic vulnerability of Pribaykal'ye (I:10, version 1)



Key: 1. Ulan-Ude; 2. Yelantsy; 3. Irkutsk; 4. Irkut; 5. Arshan; 6. Angarsk; 7. Cheretkhovo; 8. Oka; 9, Iya; 10. Lena; 11. Nizhneangarsk; 12. Upper Angara; 13. Mama; 14. Bodaybo; 15. Chara; 16. Chara; 17. Yakut; 18. Vitim; 19. Karenga; 20. Nercha; 21. Olekma; 22. Shilka; 23. Chita; 24. Ingoda; 25. Khilok; 26. Barguzin

It is possible, however, to think that the indicated increase in T_{calc} is small. Strong earthquakes are quite rare (and only they can give the corresponding quaking at the distances). In any case, when calculating T_{calc} for force 5 and higher in Irkutsk the strip between the parallels of 44 and 48° north latitude and 91 to 96° east longitude located to the south dropped out of the investigation. Analogously, for Kabansk, similar strips were between 44 and 48° north latitude and the meridians of 93.5 and 98° east longitude.

In particular, this can explain the fact that T_{calc} for Irkutsk (7 years) turns out to be greater than T_{obs} (4 years), although other causes, above all, the errors in determinations, are possible here. The difference for force 6 in Table 17 for Irkutsk (20 and 40 years) can easily occur as a result of the errors in estimating the force of the individual earthquakes. On the other hand, T_{obs} for the earthquakes with force 5 in Kabansk perhaps turned out to be higher by comparison with T_{calc} if certain shocks are not taken into account for the investigated interval.

According to Table 17, the quakes of force 7 and higher in Irkutsk must be very rare, and force 8 and higher, in practice, are absent in general. However, judging by the historical information, it is possible to think that over the last 250 years up to 3 force 8 earthquakes have been observed in Irkutsk -- in 19742, 1829 and 1862. This somewhat resembles the results obtained for Tashkent (Zakharova, Seyduzova, 1971) and it is possibly explained by the fact that the calculation for the high force earthquakes is unreliable in the given case. On the maps of the higher force seismic vulnerability Irkutsk is in the marginal zone. However, probably this is caused by other reasons, above all, failure to consider the peculiarities of the damping of the quakes in this case. It should not be forgotten that the performed calculations of the seismic vulnerability in Pribaykal'ye are the first effort; they do not pretend to the final solution of the problem and must be given in more detail and more precisely defined hereafter (in particular, it is necessary to consider the peculiarities of the damping of the quakes under various conditions, and more precisely to specify the variations of the graphs of the recurrence rate with respect to area). Therefore the estimates obtained for the seismic vulnerability are expediently used more for conclusions of a general nature but not for detailed conclusions as applied to the local areas.

Discussing the accuracy of the calculated estimates of the seismic vulnerability, it is necessary to note that an error of 1.5-2 times is entirely possible here (Riznichenko, Zakharova, Seyduzova, 1969; Zakharova, Seyduzova, 1971; Fedotov, Shumilina, 1971; Dzhibladze, Riznichenko, 1973).

The seismic vulnerability depends linearly on the seismic activity, that is, on variation of the seismic activity everywhere in the zone by two times, the vulnerability also varies by two times.

The numerical values of the vulnerability obtained for Pribaykal'ye are comparable to the results known for other regions. Similar results have been obtained earlier for Italy (Riznichenko, et al., 1970), and somewhat lower or the same vulnerability is characteristic of Eastern Uzbekistan (Zakharova and Seyduzova, 1971) and Georgia (Dzhibladze, Riznichenko, 1973). The lower vulnerability of the Crimean regions (Riznichenko, Bune, et al., 1969) and the Carpathian zone (Drumya, Popov, Stepanenko, 1971; Drumya, Popov, Reshetnikov, Stepanenko, 1971) than in Pribaykal'ye, and higher vulnerability in Kamchatka (Fedotov, Shumilina, 1971) is entirely natural, however, the excess is not so great as could be expected at first glance. The calculations of the seismic vulnerability thus determine the place of Pribaykal'ye with respect to the degree of seismic danger among other regions of the Soviet Union.

CHAPTER X. EARTHQUAKE FORECASTING

Peculiarities of the Development of the Seismic Process by the Observations of Weak Earthquakes (in Connection with the Search for Diagnostic Attributes of Strong Earthquakes)

In nature there are sets of earthquakes, about which there is no doubt that they belong to a single center zone: foreshocks and aftershocks. The intermediate position (if it is possible to call it that) between the "independent" and "related" earthquakes is occupied by swarms and groups of earthquakes combined by a defined commonness of territory (space) and, obviously, somehow interconnected in time.

The investigation of the space-time laws in the distribution of sets of earthquakes is of unquestioned interest, for during the course of the investigations it is possible to obtain data on the peculiarities of the development of the seismic process.

Thus, the study of the nature of the manifestation of the aftershock activity provides information about the development of the process in the center, the dimensions and configurations of the center zone. The analysis of the geographic distribution of the shocks in the swarms and groups permits estimates to be made of the effect of one earthquake on another; the time-space analysis of the distribution of the weak earthquakes is of interest for studying the process of the preparation of a strong earthquake, and so on. The results are presented below from studies of the enumerated and certain other aspects of the seismic process in the Baykal seismically active zone performed to discover the possibility of estimating the occurrence of strong earthquakes.

The basis for the investigations is the data on the 2500 earthquakes with $K \geq 8$ recorded by the Pribaykal network of stations in 1965-1968.

In addition, it turned out to be possible to investigate the seismic conditions of the region of the center of 20 strong earthquakes ($M > 5$) and one significant form occurring in the zone for the 1959-1968 period (Table 18). As a rule, the energy estimates for strong earthquakes were realized by the known relations between K and M derived by T. G. Rautian, the application of which is entirely admissible for Pribaykal'ye (see Chapter VI).

The observations indicate that for the earthquakes of medium strength (M to 5) the coordinates of the aftershocks and the basic shock are indistinguishable within the limits of accuracy of the observations. With an increase in energy of the main earthquake, the area occupied by the aftershocks increases. Usually in Pribaykal'ye areas of the aftershock zones have elongated shape; sometimes the epicenters of the repeated shocks are elongated in chains.

As a rule, in the areas of "normal" seismic conditions the earthquake distribution in space and in time follows the Poisson distribution, that is, each earthquake is a random independent event. The deviations, as was demonstrated by various researchers, are connected with the occurrence of aftershocks, swarms and groups of earthquakes. By the grouping phenomenon we mean the significant deviation of the distribution of the shocks in time from Poisson in areas characterized by a constant mean recurrence rate of earthquakes and not connected with the aftershocks and swarms of earthquakes (Borovik, 1972). In order to find the shocks making up the group, it is necessary to select the critical values of the size of the region and the time interval, falling into which will indicate grouping of the shock. The radius of this region would be logically given as equal to the radius of the center of the earthquake. However, for earthquakes of energy class 8-13 in Pribaykal'ye the possible errors in determining the coordinates of the centers are appreciably greater than their dimensions. Therefore the radius of the area of possible grouping was taken equal to 30 km. The calculation of the time criterion of the grouping reduced to finding the time interval such that the probability of appearance within the limits of this interval of one or more shocks is equal to a defined given low probability. In the given case P=0.005, for the corresponding average number of shocks for the grouping area.

For Pribaykal'ye, the groups include shocks occurring an area of 2800 km^2 and separated by time interval of less than 0.35 days. During a single test, the random realization of the event with the probability of 0.005 is in practice impossible. However, when isolating group earthquakes, we make not one test, but can accidentally have some number of so-called false groups. In Pribaykal'ye, excluding the false groups, 18.2% of the earthquakes belong to the groups.

Groups were isolated with values of the probability from 0.001 to 0.07 (see Fig 93). The results are the most stable for the probabilities of 0.005 to 0.01 which is expedient to use in practice. Now let us return to the dependence of the grouping effect on the dimensions of the area. The following sizes of the areas were selected -- 80, 314, 1200, 7800 and 2X10^5 km^2. For each case a study was made of the number of true groups and the grouping coefficient γ -- the ratio of the number of group earthquakes to the total number. The grouping coefficient increases with a decrease in size of the grouping area until inaccuracy begins to be felt in determining the position of the epicenters, that is, when isolating the group earthquakes it is possible to use any value of the grouping area not exceeding 3000 km^2.

Table 18

Data on the Sequences of Repeated Shocks of Pribaykal'ye Earthquakes in 1959-1968

Дата (1)		Координаты (2)		M	L, км	S, км²	Q, км³	n	Примечания (3)
		φ° N	λ° E						
29/VIII	1959	52,6	107,1	$6^3/_4$	60	1800	>4000	224	
11/XI	1962	55,9	113,2	6	60	1200	3300	119	
30/VIII	1966	51,7	104,5	$5^3/_4$	25	—	~1000	5	Для определения S данных мало (4)
31/VIII	1968	56,4	115,8	$5^3/_4$	(17)	(130)	(2000)	67	
13/VIII	1962	53,7	108,5	$5^1/_4$	35	(600)	2300	25	
22/I	1962	52,4	100,3	$5^1/_4$	15	—	—	6	
26/XI	1968	55,9	111,5	5,3	18	(60)	(300—450)	4	
11/II	1967	52,0	106,4	$5^1/_4$	(15)	—	—	3	
31/XII	1966	55,6	110,8	~5	35	600	2500	363	Рой землетрясений (5)
15/I	1967	55,6	110,8	$5^1/_4$	—	—	—	—	
10/II	1963	52,6	106,8	5	15	30	750	9	
21/VII	1968	55,2	113,4	5	13	80	(650)	69	
1/XII	1963	55,9	112,0	$4^3/_4$—5	20	(200)	(1000)	6	
25/VI	1961	52,4	106,5	$4^3/_4$—5	5	—	—	2	
27/VII	1961	54,1	110,0	$4^3/_4$	25	—	—	5	
8/I	1963	51,3	101,9	$4^3/_4$	10	(50)	—	3	
11/XII	1964	52,4	106,3	$4^3/_4$	15	—	—	4	
9/I	1963	54,7	111,8	4	10	(70)	—	2	
1/VII	1962	51,7	101,9	$3^3/_4$—4	12	—	—	3	
10/X	1963	51,8	105,1	$3^3/_4$—4	5	—	—	2	

Key:

1. Date
2. Coordinates
3. Notes
4. For determination of S there are few data.
5. Earthquake swarm

Note. 1. n is the number of shocks in the series considered during processing; L is the extent of the aftershock zone; S is the area of the aftershock zone; Q are the dimensions of the region of preparation of the earthquake. 2. The values of M were taken from the seismologic bulletin of the seismic station network of the USSR and the collections on "Earthquakes in the USSR."

Previously it has already been pointed out that the groups, just as the series of aftershocks belong to the local sets of interconnected events. The aftershocks are related by commonness of the area, in groups this relation is expressed by the effect of the centers that are close to each other. It is possible to define the limits of this effect approximately. Inside each set of group earthquakes isolated for various values of the grouping area, a study is made of the group distribution with respect to the maximum distance between shocks in each individual group. In addition, the earthquakes of which energy, classes constitute a group was taken into account. For this purpose, the difference (K_1-K_{max}) was determined, where K_1 is the energy class of the first shock in the group, K_{max} is the maximum energy class noted in the given group. From the comparison it follows that groups are most frequently encountered with a spacing between the most remote shocks not exceeding 10 km, that is, the mutual effect of the centers of the weak earthquakes appears at this distance. A more detailed analysis, unfortunately, is impossible, for the epicentral region of the earthquake center of the 8th to 11th energy classes is smaller than the region of possible position of the epicenter.

Therefore, for the Pribaykal seismic zone data were obtained on the extent of the regions, within the limits of which the centers of the group earthquakes are located and the linear dimensions of the center zones of the strong earthquakes have also been approximately determined. Therefore hereafter it turned out to be possible to perform the studies of the seismic conditions in the regions occupied by the centers of the strong earthquakes before the occurrence of the earthquake and after it. The study was made by the following diagram: 1) a study was made of the earthquake distribution over a significant area, including the future center of the strong earthquake long before its occurrence; 2) the epicentral zone of the isolated region was investigated during the period of maximum activity of aftershocks; 3) the development of the seismic process in the isolated zone after the end of the series of aftershocks was traced; 4) the discovered epicentral fields were compared.

The time intervals during which a study was made of the space-time distribution of the earthquakes before and after the occurrence of the series of aftershocks were selected usually the same, lasting several years, sometimes months, depending on the quality and quantity of the initial data, the density of the epicenters at the given point and the strength of the earthquake.

The series of aftershocks of the Central Baykal earthquake of 29 August 1969 (M=6-3/4) are presented in Fig 94 as an illustration of the processing.

The distribution of the representative earthquakes in the vicinity of Central Baykal for the periods of 1 January 1952 to 29 August 1959 is presented in Fig 94, a; the period of maximum activity of the aftershocks (29 August 1959 to 30 June 1964) is presented in Fig 94, b. From July 1964 (Fig 94, c), the activity of the aftershock zone in practice compared with the average activity of the region. The region of reduced seismic activity

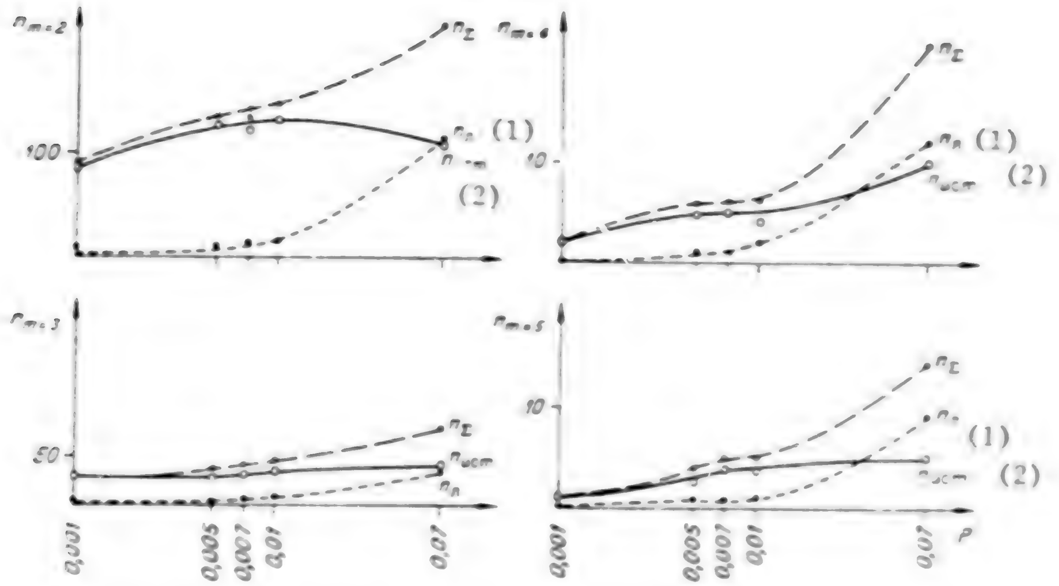


Figure 93. Grouping of weak earthquakes for various values of the probability of random occurrence of an event. n_Σ is the total number of isolated groups; n_{true} is the number of true groups; $n_л$ is the number of false groups; m is the number of groups (the numbers 2, 3, 4, 5 are the number of shocks in the group)

Key:

1. $n_л$
2. n_{true}

isolated when comparing the epicenter maps (see Fig 94, d) including the center of the earthquake, has an area on the order of 4000 km^2. Let us note its "region of preparation." The sizes of this region exceed by approximately two times the area of the aftershock zone. It is true that in the northeast the boundary is drawn uncertainly as a result of the absence of data. For comparison, a region is isolated (see Fig 95, a), the area of which was selected for convenience equal to the area of the preparation region.

The data on the variation of the activity in the region of preparation of the earthquake and the adjacent comparison region are presented in Fig 95 (the number of observations is plotted on the y-axis, and the observation time on the x-axis). As is obvious, the "period of quiet" of the preparation region lasted at least 7 years; at the same time in the surrounding areas the background of seismic activity in practice did not change.

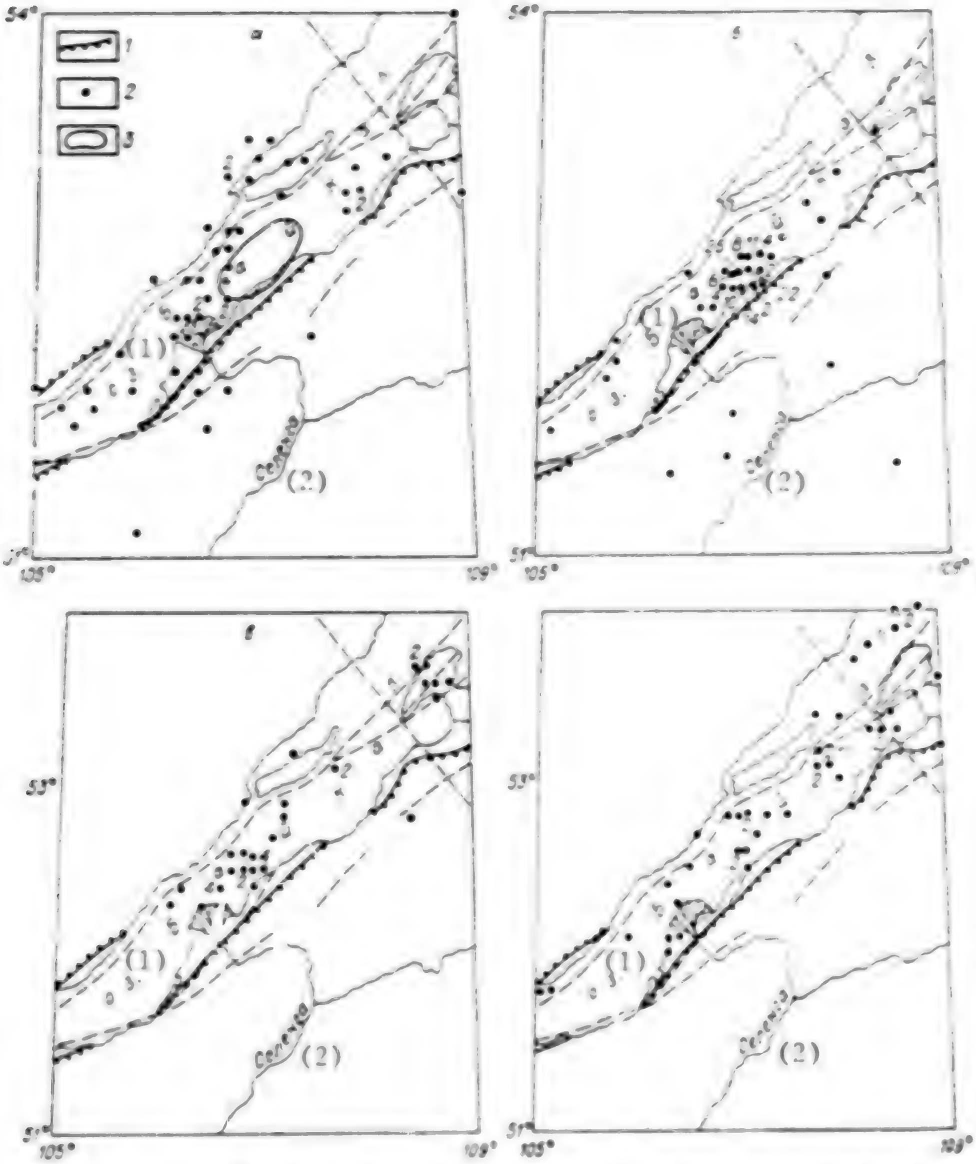


Figure 94. Analysis of the epicentral field in the vicinity of Central Baykal by the data on earthquakes with K≥10 for 1952-1970

a -- epicentral field of the region for the period from 1 January 1952 to 29 August 1959; b -- epicentral field of the region for the period from 29 August 1959 to 31 December 1960; c -- epicentral field of the region for the period from 1 January 1961 to 30 June 1964; d -- epicentral field of the region for the period from 1 July 1964 to 31 December 1970. 1 -- limit of the investigated region; 2 -- epicenters of the earthquakes with K≥10; 3 -- boundary of the aftershock zone.

Key:

1. Lake Baykal; 2. Selenga River.

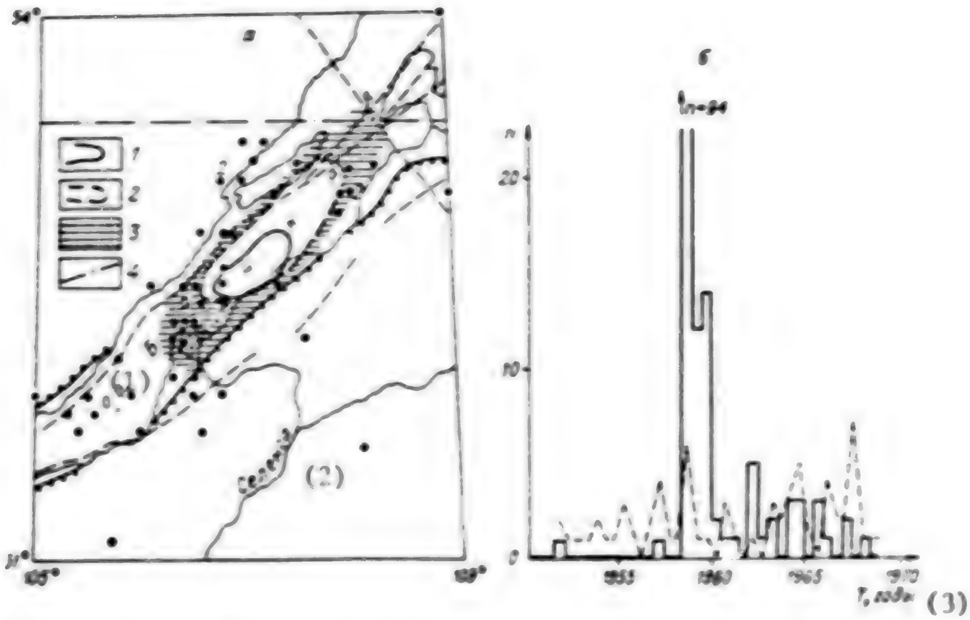


Figure 95. Seismic conditions within the limits of the region occupied by the center of the earthquake of 29 August 1959

a -- aftershock zone, region of preparation of the earthquake and region of comparison: 1 -- boundary of the aftershock zone, 2 -- boundary of the preparation region, 3 -- comparison region; b -- development of the seismic process in time in the region of preparation of the earthquake (the solid line) and the region of comparison (dashed line)

Key:

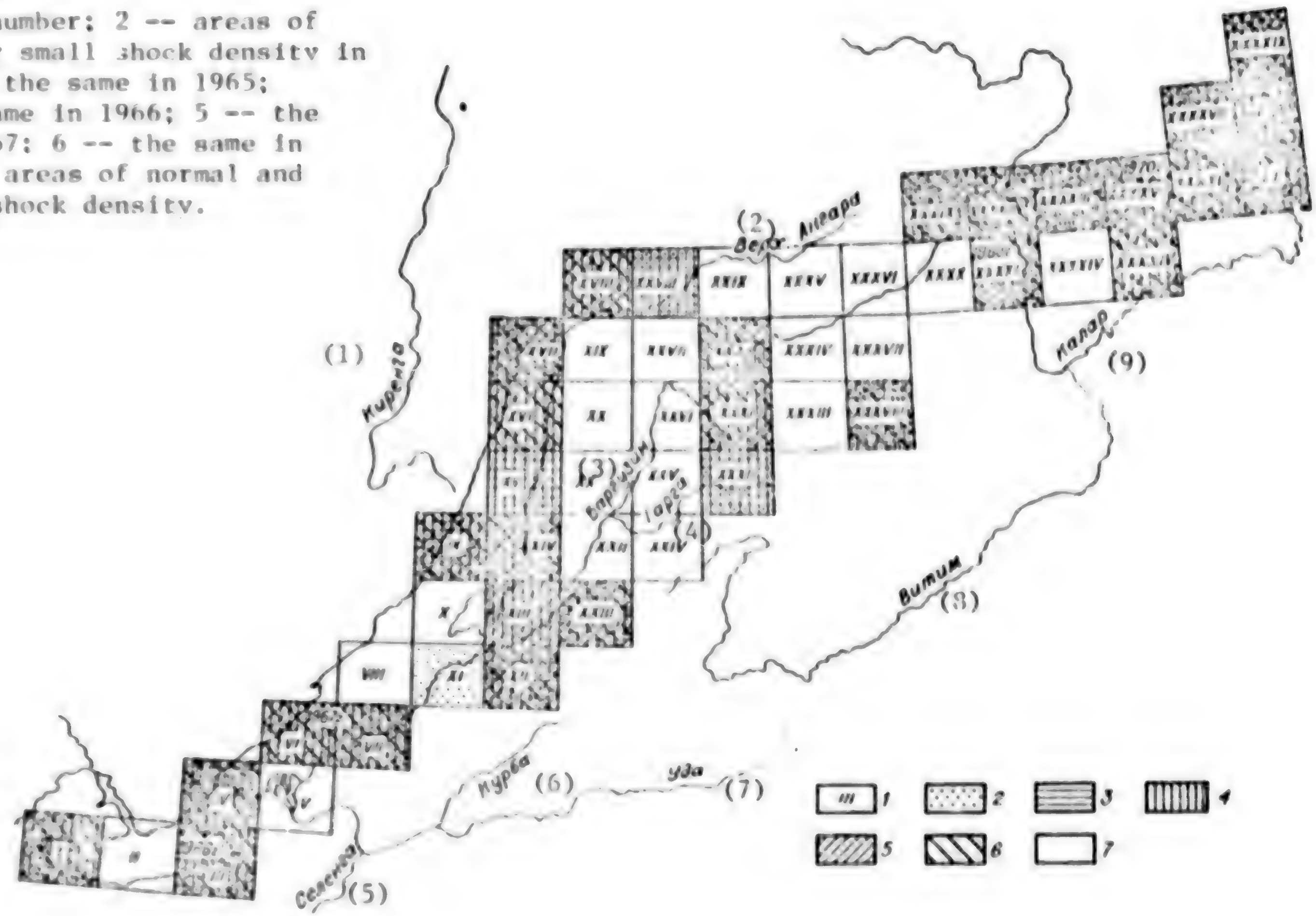
1. Lake Baykal
2. Selenga
3. T, years

The series of aftershocks of 12 strong earthquakes in 1959-1968 were processed by the same scheme. The results were found to be analogous, that is, it is possible to propose that a strong earthquake is preceded by a prolonged preparation process which develops within the limits of the significant area (Borovik, 1971).

The preparation regions have been isolated most reliably for earthquakes with magnitude M=5-1/2 and more.

Thus, for Pribaykal'ye, the preparation region of an earthquake of defined magnitude can be characterized by the parameters: Q, T_Q, n_Q, where n_Q is the number of shocks in the region Q for the period T_Q. Under the condition that the process of the occurrence of a strong earthquake is

Figure 96. Schematic of the division of the region into areas $Q=4000$ km^2.
1 -- area number; 2 -- areas of anomalously small shock density in 1964; 3 -- the same in 1965; 4 -- the same in 1966; 5 -- the same in 1967; 6 -- the same in 1968; 7 -- areas of normal and increased shock density.



Key: 1. Kirenga; 2. Upper Angara; 3. Barguzin; 4. Garga; 5. Selenga; 6. Kurba; 7. Uda; 8. Vitim; 9. Kalar

subordinate to laws discovered when investigating the seismic conditions of the regions of the centers of strong earthquakes in the past and the seismic equivalence of the individual sections of the Baykal seismic zone, the attributes Q, T_Q and n_Q can be used to discover the regions of increased seismic danger in the near future (Borovik, 1974).

The region of low activity can be isolated by construction of the maps of the distribution of the epicenters of weak earthquakes by the defined time-space areas where the spatial parameter is the dimensions of the preparation region of an earthquake of corresponding magnitude, and the time parameter is the duration of the preparation period of the earthquake of the same magnitude.

Then the isolated regions must be checked for the criterion n_Q.

The approximate values of Q, T_Q for the corresponding magnitudes are indicated above. It is necessary to find n_Q for which the quiet can be assumed connected with the formation of the preparation region. For this purpose, selecting the value of the low probability of the random realization of the event within the limits of the defined region, let us find the probabilities of occurrence of 0, 1,..., n_Q shocks. If the number of shocks n in the region Q for the period T_Q is less than that selected by us ($n \leq n_Q$), then the quiet can be considered nonrandom.

For probability P=0.005, the possibility of isolating the region where earthquakes of magnitude $M \geq 5$-1/2 are probable was discussed under the condition that the average number of shocks in any elementary space-time area is identical for the entire investigated zone.

The annual distribution maps for the earthquake epicenters with $K \geq 8$ are constructed with respect to areas of Q=4000 km^2 for 1964-1968. Within the limits of this area, during the year earthquakes of energy class 8 and higher must be absent, that is, n_Q=0.

When comparing the maps obtained, 14 years were isolated corresponding to the parameters Q, T_Q, n_Q: I, III, VII, IX, XII, XIV, XVII, XXXI, XXXIX, XXXXII, XXXXIII, XXXXVIII, XXXXIX, LI in Fig 96. All of the strong earthquakes of $M \geq 5$-1/2 noted for 1964-1968 occurred within the limits of the isolated areas (III -- 1966; III -- 1967; XXXII -- 1968), that is, for Pribaykal'ye the probability of the occurrence of a strong earthquake with $M \geq 5$-1/2 within the limits of the section with anomalously low activity is higher (0.2) than the probability of a strong earthquake within the limits of the area of normal or increased activity.

The simple division into elementary areas and calculation of the number of epicenters following into each area do not permit sufficiently reliable determination of the dimensions of the regions of low concentration of epicenters. Therefore, another density map was constructed: an area 0.4° north latitude X 0.6° east longitude was shifted by 0.1° latitudinally and longitudinally, and in each of these shifted areas the number of epicenters was calculated (Fig 97). Against the background

of uniform normal density distribution (see Figure 97, 2) areas of reduced density were isolated (see Fig 97, 4). The strongest earthquakes or significant swarms in the near future are more probable within the limits or on the boundaries of the defined regions and in the regions of normal or increased shock density.

It is natural that the 5-year observation interval which we could analyze is insufficient to obtain reliable forecasting attributes of a future strong earthquake. The most reliable results can be obtained when analyzing the seismicity of the area for the longest time interval possible. Unfortunately, we do not have the possibility of performing such an analysis. Only indirect estimates can be made of the seismicity of the isolated regions of reduced density: analysis of the earthquake epicenter map with $K \geq 8$ for 1964-1968, distribution of strong earthquakes for 200 years (1771-1971), centers of paleoseismodislocations and schematics of the basic fault systems. The comparison confirms the correctness of the possible appearance of strong earthquakes in the isolated regions.

Within the boundaries of the I region on 28 March 1970, a strong earthquake occurred (M=5.5); in May 1970, a strong earthquake was noted (M=5.6) within the limits of region V. In 1973 an earthquake with M=4.5 and a significant swarm within the limits of regions II and IV were observed.

Thus, a detailed analysis of the seismic information for a quite short observation period made it possible to obtain results that deserve attention:

1. On the basis of the investigation of 20 series of aftershocks and one swarm, the relation was established between the maximum linear dimensions of the aftershock zone and magnitude of the main earthquake.

2. The investigation of the grouping of the earthquakes not belonging to the series of aftershocks and swarms demonstrated that out of all of the earthquakes (K=8-11) recorded in 1964-1968, 18.2% belong to groups. The mutual effect of the grouped earthquakes on each other is exhibited at distances not exceeding 10 km.

3. On the basis of the investigation of the regions of the centers of 12 earthquakes with M=5 and more it was established that before each of them there is some region of calm, the dimensions of which are proportional to the magnitude of the earthquake and which can be considered as the preparation region.

4. The investigation of the inverse law -- the relation of the "empty" regions (corresponding to the parameters Q, T_0, n_0) to the subsequent occurrence of strong earthquakes -- demonstrated that the regions of calm can be considered as regions with increased probability of the occurrence of strong earthquakes or significant swarms.

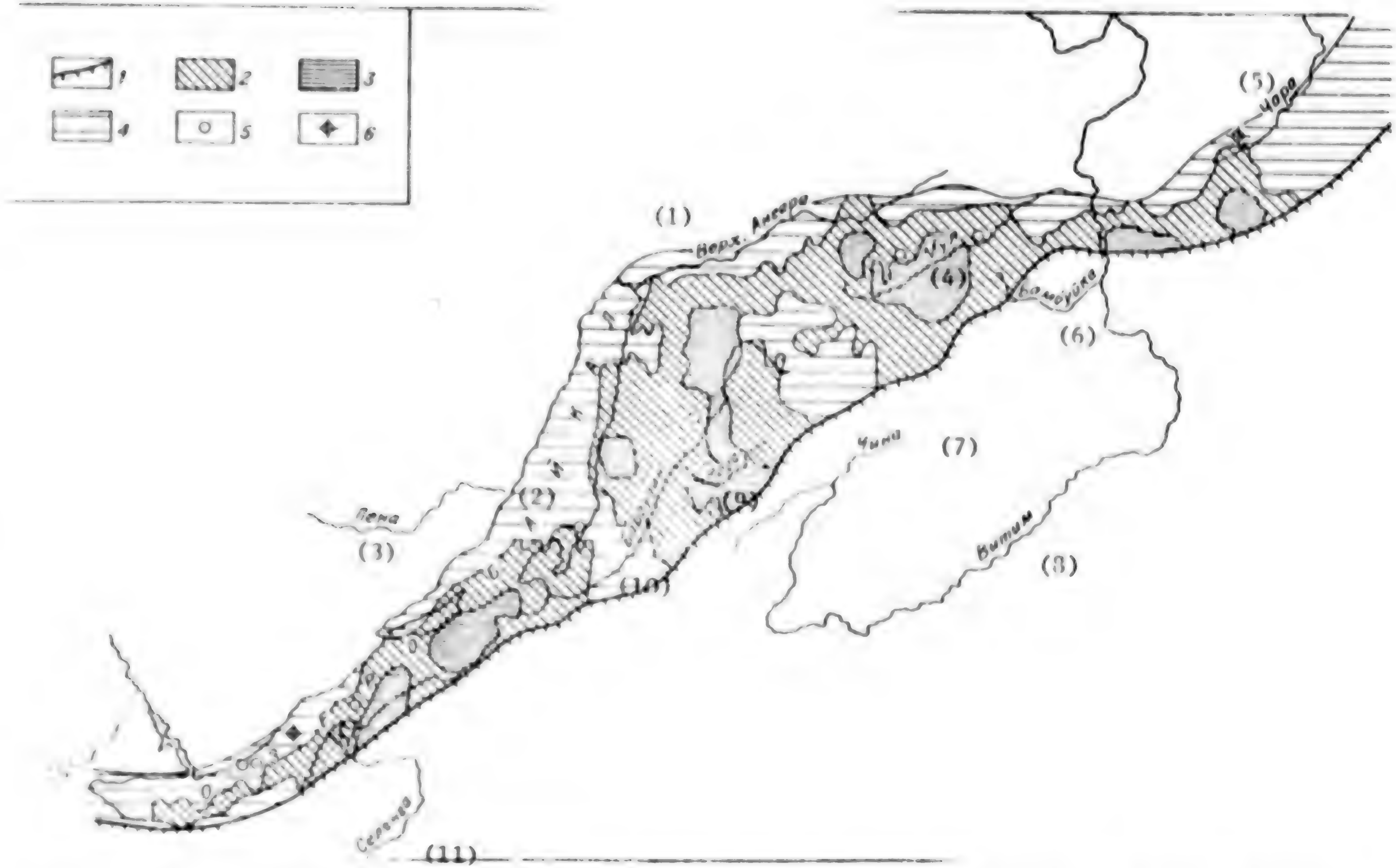


Figure 97. Identity map of earthquake epicenters (the range of existence of the "normal" seismic background was obtained for small value of the probability of random realization of the event P=0.005: $12 \leq N_{norm} \leq 42$).
1 -- boundaries of the investigated region; 2 -- sections of "normal" density; 3 -- sections of increased shock density; 4 -- sections of reduced shock density; 5 -- earthquake epicenters with $M \leq 5$ for 1968-1970; 6 -- earthquake epicenters with M=5-1/2 for 1968-1970.
Key: 1. Upper Angara; 2. Lake Baykal; 3. Lena; 4. Muya; 5. Chara; 6. Bambuyka; 7. China; 8. Vitim; 9. Garga; 10. Barguzin; 11. Selenga

Long-Range Forecasting of the Seismic Activity According to the Geophysical Data

The basic materials for permitting characterization of the seismicity of one region or another are the results of the processing of instrument observations of earthquakes. However, the uniform seismostatistical material for the southern part of Eastern Siberia has been accumulated only since 1962. In accordance with the fact that the observation time is short, this material characterizes both the long-term and short-term (random) components of the seismic process. In a number of regions, the random component can predominate. Therefore it is difficult to forecast the future seismic activity with respect to seismostatistics. To a known degree the indicated deficiency in studying the seismicity is filled by the paleoseismogeological method. Seismogeological studies in the southern part of Eastern Siberia revealed a large number of paleoseismodislocations, and an approximate estimate was made of the force of the earthquakes as a result of which the indicated paleoseismodislocations were formed. The material obtained indicates that the increased seismicity was observed in individual sections of the described territory hundreds and even thousands of years ago. However, as a result of intense effect of the denudation processes up to the present time, traces only of the strongest disastrous earthquakes have been preserved by which, of course, it is impossible to obtain a complete representation of the manifestation of the seismic process in the entire investigated territory of Eastern Siberia.

The information about strong earthquakes in the 17th to 19th centuries that has come down to us, the broad material on paleoseismodislocations in accordance with the seismostatistical data permit us to state that the increased seismicity during the prolonged period is characteristic of a comparatively clearly located area in the Baykal rift zone. The continuation of the process of tectonic activation in the Baykal rift zone is indicated by numerous earthquakes -- 3000 or more per year.

The phenomenon of seismicity of the Baykal rift zone cannot be considered isolated, separated from the various geological-geophysical characteristics of the region. The deep geophysical studies in recent years have established that the zones of the latest tectonic activation -- both oceanic and continental rift systems -- have a number of specific features: contrast of the forms of modern relief, the existence of large rift basins filled with thick Cenozoic deposits, increased heating of the earth's depths, the presence of a zone of reduced velocities in the upper mantle and many other characteristics. The Baykal rift zone, according to the data of numerous studies (Bulmasov, 1959; Zorin, 1971; Gornostayev, et al., 1970; Misharina, 1967, 1972; Novoselova, 1972 a, b; Puzyrev, et al., 1974) is also characterized by surface and deep structure of the earth's crust significantly different from the bordering territories and by the specific peculiarities of the geophysical fields respectively (see Chapter IV). The variation of the surface and depth structure of the earth's crust caused by the riftogenic process takes place slowly, and the characteristics

of the relief, the structure of the earth's crust and the geophysical fields available at the present time are the result of prolonged development of the region. Inasmuch as the modern seismicity of the Baykal rift zone and with peculiarities of its surface and deep structure characterize various aspects of the same tectonic process, the theoretical possibility of obtaining the representation of the long-term component of the seismicity from a comparison of the seismostatistical data with the different geological-geophysical parameters characterizing the latest tectonic activity is noted. However, for extrapolation of the basic peculiarities of the long-range component of the seismicity in the modern stage of development of the region, proofs are needed of the preservation of the main trends in the appearance of the tectonic process. We have certain proofs of this at our disposal. First of all, this is the manifestation of increased seismicity in almost the same frame of the region of Cenozoic activation where a special surface structure of the earth and its depths is observed. Then, comes the preservation of the basic peculiarities in the development of uplifts and basins. The formation of the generated basins in the Kodar, Udokan and Khamar-Daban ridges, the variation in rates of sediment accumulation are phenomena of a local order.

Thus, having information available about the long-range component of the tectonic process in the form of geomorphological parameters and the characteristics of the geophysical field and data or the modern seismicity (we are talking about seismic activity), it is possible to try to establish quantitative relations between them and, in the presence of the latter, to determine the long-term component of the seismicity.

The study of the relations of seismicity to various geological-geophysical parameters has acquired broad scale at the present time. Quite frequently the researchers have alerted themselves to the establishment of the qualitative relations of the investigated parameters (Gamburtsev, 1954, 1955; Gamburtsev, Veytsman, 1956; Ibragimov, 1970; Drumya, 1973; Kuznetsov, et al., 1971; Karagityan, Manukyan, 1971). The works aimed at obtaining quantitative characteristics of the relations of the seismicity to the geological-geophysical parameters are of significantly greater interest (Riznichenko, et al., 1969; Tal'-Virskiy, et al., 1971; Butovskaya, Sokolova, 1970; Gorshkov, Shenkareva, 1970). However, only in the papers by V. I. Bune, M. Ye. Artem'yev, N. Sh. Kambarov (1971) and N. Sh. Kambarov (1971) was an effort undertaken to estimate the seismic danger of the territory on the basis of the quantitative relations of seismicity, isostatic anomalies of the gravitational force and their gradients.

In Pribaykal'ye, the studies of the quantitative relation of the seismic activity to the relief and the gravitational field were begun by Yu. V. Riznichenko, Yu. A. Zorin and K. V. Pshennikov (Riznichenko, et al., 1969). The seismic activity map compiled by K. V. Pshennikov by the

method of summation of the earthquakes using a constant averaging area for the period from 1962 to 1966 was compared with the altitudes of the average relief (the dimensions of the averaging area were 30X30 km), the moduli of the altitude gradient of the average relief (the dimensions of the averaging area are 45X45 km) and averaged isostatic anomalies calculated by Yu. A. Zorin by the simplified method proposed by him. The pair correlation was fulfilled for the entire territory of the Baykal rift on the whole and separately for its flanks and central regions. It turned out that over the entire territory there is no clear quantitative interrelation between the altitudes of the average relief and the seismic activity. The pair correlation coefficient is close to zero. It increases to -0.34 ± 0.15 only on the flanks of the rift system.

The modulus of the altitude gradient of the average relief is correlated with the seismic activity somewhat better: $r = 0.36 \pm 0.09$ and preserves the order of magnitude both in the individual sections of the territory and on the whole throughout the rift zone.

The relation between the averaged isostatic anomalies and the seismic activity turned out also to be reliable, but weak ($r = 0.23 \pm 0.09$). On making the transition from one section of the rift to the other, the nature of the relation did not remain constant. The results obtained led to the conclusion that the quantitative relations between the seismic activity and some of the geomorphological-gravimetric parameters in the linear and quadratic forms exist reliably, but they are weak and cannot be used for forecasting the long range average seismic activity.

The further study of the interrelation of seismic activity and the geological-geophysical parameters was continued by N. R. Novoselova and Yu. A. Zorin in the direction of finding an improved form of the relation and the set of parameters which would have a closer relation to the seismicity. For comparison, a map of the seismic activity is used which was constructed at the Seismology Laboratory of the Institute of the Earth's Crust of the Siberian Department of the USSR Academy of Sciences by the method of constant accuracy on seismostatistical data for 1965-1968. The dimensions of the averaging areas varied from 96 to 18,000 km^2, and accuracy of determining the seismic activity turned out to be equal to 35%. The seismic activity was calculated by the generally accepted formula in the shocks of the network with a step size of 0.2° with respect to latitude and longitude. All of the earthquakes were used beginning with the 8th energy class. The 10th class was taken as K_0. The angular coefficient of the recurrence rate graph for using the set of earthquakes is 0.485.

The described map of seismic activity is in general feature similar to that in the paper by Yu. V. Riznichenko, et al. (1969), but it differs in detail. This difference is caused by the use of the seismostatistical material for various years and the application of various construction procedure. It is necessary to note that the correlation coefficient

between the values of the seismic activity of the two maps is 0.6. However, when repeating the correlation of the seismic activity with respect to the new map to the gradients of the averaged altitudes and isostatic anomalies, estimates were obtained for the degree of linear and quadratic relations having the same order as in the earlier paper (Riznichenko, et al., 1969).

The modulus of the altitude gradients of the upper Cretaceous to Paleogenic planation surface deformed by the latest movements, the modulus of the horizontal gradients of the gravitational anomalies in the Bouguer reductions and the isostatic and also the values of the gravitational anomalies in the Bouguer reduction were used as the new parameters with which a comparison of the seismic activity was made. The maps of the moduli were constructed by the general principles described in the paper by Yu. V. Riznichenko, et al., (1969). The gradients were calculated by the averaging areas on the order of 9000 km^2. The latter value was obtained as the arithmetic mean of the dimensions of the earth used to calculate the seismic activity.

The pair correlation coefficients characterizing the linear form of the relation turned out to be reliable, but low.

Then the set correlation of the seismic activity with the sets of geological-geophysical parameters was carried out. Several versions of the combination of the correlated parameters were tested, but the values characterizing the dismemberment of the relief, the variability of the local component of the gravitational field and the values of this field themselves always participated here. In addition to the linear relation, the quadratic, cubic, logarithmic and semilogarithmic forms were also tested. The best form of the relation turned out to be the semilogarithmic (the logarithm of the seismic activity was considered to be a linear function of the geological-geophysical parameters). With this form of the relation, the maximum set correlation coefficient (0.73 ± 0.05) was obtained for the seismic activity, the altitude gradients of the average relief, the gradients of the isostatic anomalies and the Bouguer anomalies respectively.

The regression equation has the form[1]

$$A_{10} = 2.3 \exp (75.58 \cdot |\mathrm{grad}\ h_{cp}| + 0.1 \cdot |\mathrm{grad}\ g_{iz}| - 0.01 \cdot g_b - 4.02) \quad (1)$$

A map of forecasting the long-range component of the seismic activity was constructed by this equation. The analysis of the map is presented in the paper by Yu. A. Zorin and M. R. Novoselova (1972).

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[1] All of the calculations connected with the correlation analysis and determination of the coefficients of regression equations were performed on the BESM-4 computer of the Eastern Geophysical Trust (Irkutsk).

In 1972 S. I. Golenetskiy and G. L. Myl'nikova constructed a new map of the seismic activity by the method of summation of the earthquake with a constant averaging area (the provisional dimensions of the area remained constant). Its similar characteristic is presented in Chapter VIII. Here let us note that the unquestioned advantage of the new map, in contrast to the previously compiled ones, is that it encompasses a large amount of seismostatistical material (1962-1971).

Naturally it could be hoped that this map would give a more objective characteristic of the seismic activity and would be more advantageous for determination of its long-term component. The map was constructed in two versions: considering all of the earthquakes and with exclusion of the swarms of weak shocks.

In view of the fact that the averaging area has appreciably smaller dimensions (988 to 1321 km^2) by comparison with the average area used previously, the necessity arose for transformation of the maps of the geological and geophysical parameters respectively (to present the dimensions of the parameter averaging areas in accordance with those which were used for calculation of the seismic activity).

The correlated values of the seismic activity and the geological-geophysical parameters were selected in the shocks of the 45X15 km network. The set correlation coefficient turned out to be equal to 0.75 ± 0.05. The regression equation has the form

$$A_{10} = 2.3 \cdot \exp\left(80.03 \cdot |\mathrm{grad}\ h_{cr}| + 0.07 \cdot |\mathrm{grad}\ g_{12}| - 0.013 \cdot g_B - 4.90\right) \quad (2)$$

A comparison of equations (1) and (2) indicates that their coefficients are close to each other. Thus, in spite of the different initial seismostatistical material, the operation of planation of the series using stably defined geological-geophysical parameters leads to close results. This permits the conclusion to be drawn that as a result we obtained the description of the actually stable (long-term) component of the seismic process.

It must be more precisely determined that the presented equation (2) was obtained as a result of comparing the geological-geophysical parameters with the total values of the seismic activity (that is, with those which were obtained when considering all of the earthquakes beginning with their given representative class). Using the maps of the seismic activity with the excluded earthquake forms, in practice the same equation is obtained (the differences in the coefficients are statistically reliable). This means that the proposed procedure automatically insures exclusion of the forms of weak earthquakes if these seismic events are random.

Let us try to explain the existing relations of the seismic activity to each of the parameters entering into equations (1) and (2). The modulus of the altitude gradient of the averaged relief is directly proportional

to the modulus of the horizontal velocity gradient of the latest vertical movements. The physical meaning of the relation of the last value to the seismic conditions is generally known (Gzovskiy, 1959, 1963). Under natural conditions, for nonuniformity of the earth's crust, this relation is entirely naturally of a statistical nature; therefore in individual sections its violation is entirely admissible.

The physical essence of the relation of the seismic activity to the gravitational field is not so obvious. The following arguments help to explain it. In Chapter II it was pointed out that the Baykal rift zone in the Bouguer anomaly field corresponds to the extended regional minimum (more precisely, the system of minima) which, judging by the deep seismic soundings, is caused by the presence of the region of dispersion of the upper mantle (see Chapter IV). The rise of the dispersed material from great depths obviously is the basic cause for riftogenesis (Artem'yev, Artyushkov, 1968; Zorin, 1971), to one of the manifestations of which the increased seismicity of the region belongs. The intensity of the riftogenesis obviously is directly related to the volume of material accumulated under the crust. On this level the correlation of the seismic activity to the intensity of the Bouguer anomaly becomes understandable.

The relation of the seismicity to the horizontal gradients of the local anomalies is assumed to be explained by the fact that the maxima of the latter fix the fractures. However, when using the gradients of the isostatic anomalies of the averaging area on the order of 40 km in diameter for the calculation, the peaks of the gradients can only in individual cases correspond to specific large faults. The analysis of the map of the modulus of the gradients of the isostatic anomalies indicates that the increased values of this parameter are characteristic of the entire rift zone as a whole, that is, in generalized form it reflects only the degree of contrast of the local anomalies (the regional component of the field is completely excluded by isostatic reduction). The contrast of the local anomalies is caused primarily by the presence of a thick series of Cenozoic deposits in the large (but comparatively narrow) rift basins of the Baykal, Barguzin and other types. Therefore the relation of the seismic activity to the moduli of the gradient of the isostatic anomalies indirectly reflects the inheritance of the modern tectonic movements expressed in the seismicity from the movements of the entire latest stage. This is valid also with respect to the remaining used parameters. The contrast of the local gravitational anomalies is caused, in addition, by increased heterogeneity of the upper layer of the earth's crust. As M. R. Novoselova (1972) demonstrated, this is a specific feature of the Baykal rift zone by comparison with the bordering territories. The direct consequence of this is a reduction in the mechanical strength of the crust material which under the conditions of the tectonic activation promotes destruction of the continuity of the material and, consequently, an increase in seismicity. Ye. V. Karus and I. Ye. Rezanov (1971) indicate that the sections of articulation of the materials with different physical properties are most favorable for the manifestation of seismicity.

Figure 98. Map of the long-term seismic activity of Pribaykal'ye. Compiled by M. Novoselova. 1 -- isolines of the long-term component of the seismic activity; 2 -- boundary of the Baykal rift zone (according to Yu. A. Zorin, 1971)

Key:

1. Selenga; 2. Irkutsk; 3. Irkut; 4. Kimoy; 5. Angara; 6. Kirenga; 7. Chaya; 8. Greater Chuya; 9. Lena; 10. Upper Angara; 11. Chara; 12. Olekma; 13. Nyukzha; 14. Kuanda; 15. Muyakan; 16. Muya; 17. Taipa; 18. Tsinikam; 19. Kalar; 20. Kalakan; 21. Tungir; 22. Amalat; 23. Vitim; 24. Nercha; 25. Shilka; 26. Argun'; 27. Chita; 28. Onon; 29. Ingoda; 30. Chikoy; 31. Khilok; 32. Uda; 33. Barguzin; 34. Lake Baykal.

Using equation (2) and the values of the above-mentioned parameters, we calculated the long-term component of the seismic activity (Fig 98) for the entire territory of the Baykal rift zone. It appears useful to us to compare the picture obtained with the initial data (seismostatistical) on the seismic activity. In this comparison three cases are theoretically possible:

1. Complete coincidence of the initial and forecasting maps. This indicates the absolute preservation of the trend in the development of the tectonic process and the unconditional suitability of the initial map of the seismic activity for the long-range forecasting of the place and the strength of the earthquakes. However, the sections for comparison of the initial and forecasting map are few. They have small area and are arranged primarily around the periphery of the Baykal rift zone.

2. The values of the long-term seismic activity are higher than on the initial step. Beginning with the statement of the problem itself, in this case we can show that the reduction in seismic activity in such areas is a temporary phenomenon. It is impossible to guarantee that this reduction will last a long time in the future. On the contrary, the tectonically active sections in the recent geological past in which the last 5 to 10 years the activity is relatively dropped, can correspond to the preparation zones of strong earthquakes. This conclusion agrees well with the data of N. S. Borovik, et al., (1971) regarding the formation of such zones in a few years before the strong earthquakes.

The regions with such relations of modern and long-term seismic activities include the southern part of the Baykal basin, the Tunkinskaya basin and its vicinity and also the northeastern part of the northern Baykal basin.

3. The values of the forecast long-term component of the seismic activity are lower than on the initial map. Such relations are characteristic for the regions where the geological-geophysical indexes of the tectonic activity are comparatively low, and the modern seismicity is high. These regions include primarily the northeastern part of the Baykal rift zone. This has served as the main reason for the assumption that the riftogenesis process develops in the northeasterly direction, encompassing the new territory in which noticeable rearrangement of large volumes of the earth's crust have still not succeeded in occurring, and the standard rift structures are still morphologically poorly expressed (Solonenko, V. ,1968b).

Strictly speaking, our data on the quantitative relations of the geological-geophysical indexes to the seismic activity say nothing for or against this hypothesis. Formerly, the latter regions are entirely equivalent to the sections where the long-term component of the activity is greater than modern. Actually, for the statistical approach (in the process of solving the problem of the equalization of the series) the deviations in different directions from the regression equation are equiprobable. We can assume

that the observed increase in seismic activity is a temporary (random) phenomenon. However, this trend can exist for tens and hundreds of years. If any industrial or other object is destroyed by a strong earthquake, then the consideration of the latter in the category of random, irregular events is of little comfort. Therefore we assume that in such regions, determining the seismic danger, it is necessary to be oriented toward modern high activity and not belong to a component. This "overinsurance" is entirely justified when we are dealing with such destructive forces of nature as an earthquake.

Thus, when estimating the seismicity we recommend the use of both the map for forecasting the long-term component of the seismic activity and the initial map of this parameter, in each region giving preference to the one for which the greater level of seismicity is indicated. Fig 99 shows the summary map of the maximum possible values of the seismic activity constructed by the indicated procedure.

It is entirely natural to state the problem of how reliable the information is about the long-term component of the seismic activity obtained by the geological-geophysical parameters with a set correlation coefficient of 0.75. We have already noted above that the correlation coefficient between the values of the seismic activity calculated for the different time intervals will be a total of 0.6. Moreover, the correlatability between the values of the activity calculated by L. A. Anisimova and G. L. Myl'nikova (1971) by the method of constant accuracy and the method of equal areas for the same year of 1970 turned out to be on the level of 0.75. Thus, the reproducibility of the value itself on varying the procedure and the time interval turns out, unfortunately, to be low. With respect to statistical reliability the forecasting map for the long-range component of the activity is not inferior to the initial maps.

On the basis of what has been discussed, it is possible to draw the following conclusions:

1. In the Baykal rift zone the modern seismic activity reveals a quite close set correlation with the moduli of the gradient of the average relief, the gradient of the isostatic anomalies and the Bouguer anomalies themselves. All of the enumerated factors characterize the total effect of the latest tectonic movements.

2. The set regression equations permits determination of the long-term component of the seismic activity. The map of this component offers the possibility of isolating potentially dangerous sections in seismic respects characterized at the present time by a comparatively quiet seismic regime.

3. The use of the maps obtained for seismic regionalization is expedient in combination with the seismostatistical material and information about the paleoseismodislocations.

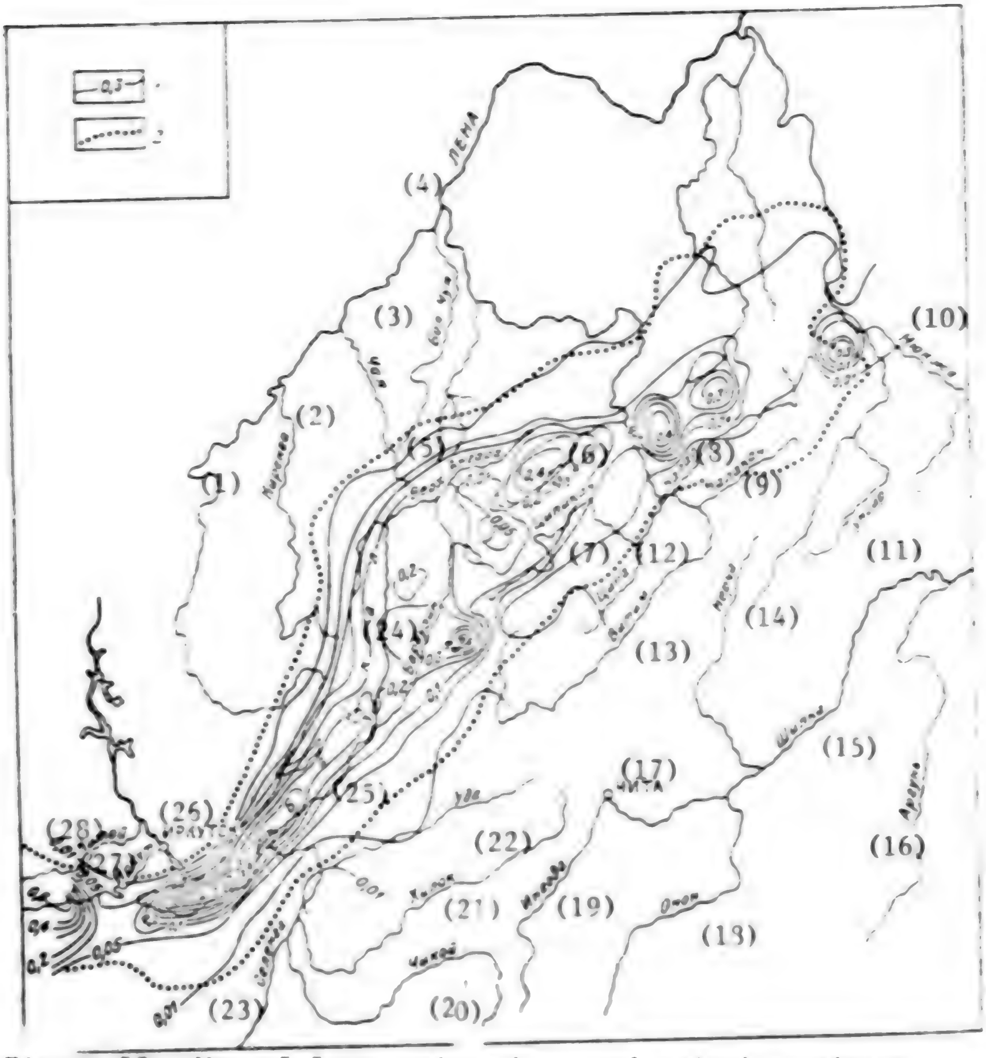

Figure 59. Map of forecasting the total seismic activity (long-term and short-term component) of Pribaykal'ye. Compiled by M. Novoselova and L. Bogatova.

1 -- isolines of the forecast total seismic activity; 2 -- boundary of the Baykal rift zone (according to Yu. A. Zorin, 1971)

Key:

1. Karenga; 2. Chaya; 3. Greater Chuya; 4. Lena; 5. Upper Angara·
6. Muya; 7. Tsinikan; 8. Kalar; 9. Nalakan; 10. Nyukzha; 11. Tungir;
12. Tsipa; 13. Vitim; 14. Nercha; 15. Shilka; 16. Argun';
17. Chita; 18. Onon; 19. Ingoda; 20. Chikoy; 21. Khilok; 22. Uda;
23. Selenga; 24. Barguzin; 25. Lake Baykal; 26. Irkutsk; 27. Irkut;
28. Kitoy.

4. The proposed procedure for determining the long-term component of the seismic activity can be recommended also for other seismic regions, especially for those where the network of seismic stations is weakly developed.

CHAPTER XI. NEOTECTONICS AND SEISMOTECTONICS

In the territory of the mountainous belt of Easter Siberia during the process of Cenozoic activation, various geological-geomorphological, neotectonic and seismic processes appeared broadly. The complex seismic geological studies of this complex region made it possible to establish both the general features and the differences of the neotectonic zones entering into it and individual elements of the morphostructure here.

The neotectonics of the mountain belt of Eastern Siberia and the adjacent part of the Siberian platform has been considered by us in the seismotectonic aspects. This will permit concentration of attention on the neotectonic movements promoting the formation of morphostructures with different seismogeological relations and the nature of manifestation of the earthquakes. The young movements converted the ancient (precenozoic) structures and created neotectonic zones in the development of which the phenomena of inheritance are closely combined with sharp rearrangement of the ancient structural plan (for example, the Transbaykal block-wave and Baykal rift zones). In seismotectonic respects, this is felt primarily in the different seismic potential of such regions and the structural elements of the different morphogenetic type entering in them.

Seismotectonics -- part of the latest tectonics -- are considered by some researchers in the narrow sense as the division which studies the occurrence, the course and the surface effects of strong earthquakes (Vardanyants, 1935; Svyatlovskiy, 1955; Gofshteyn, 1963; and so on). Obviously, it is more correct to consider the problems of seismotectonics on the broader level -- primarily in the revelation of the genetic relation of the modern seismicity to the geological-structural development of one region or another (Gubin, 1950, 1960; Petrushevskiy, 1955; Florensov, 1960, 1968; ACTIVE TECTONICS...., 1966; SEISMOTECTONICS...., 1968, 1975a, b; the Gobi-Altay earthquake, 1963; Allen, et al., 1965, and so on). In one way or another the main goal of the seismotectonic studies must consist in the fact that on the basis of geological-geophysical analysis of the relation of the geological structure-morphostructure-earthquake establishment of the seismogenic structures and determination of their seismic potential constitute one of the most important elements of the set of attributes by which seismic regionalization is carried out.

From the understanding of the morphostructures as genetically unique complexes of the tectonic-orographic elements formed by the latest endogenic movements comes the importance of their seismotectonic classification with the corresponding estimate of the relative potential seismicity. Here it is most important to discover the geodynamic type and nature of the movements causing genetic variety of the morphostructures and modern geomorphological contrasts. Often, especially when there is a shortage of seismological and seismogeological data, this estimate is complicated and to some degree is subjective. Nevertheless, the joint analysis of the geological-geophysical, neotectonic and seismological data will permit quite reliable isolation of the basic epicentral zones of the possible maximum earthquakes.

The basis for this is the seismotectonic map (Fig 100) reflecting the different structural-geological and morphostructural criteria of the seismic processes occurring in the earth's crust -- the type and differentiation of the morphostructures and the dislocations of the break in continuity, the active faults and the main "seismogenerating" zones, the paleoseismogenic structures and other seismogeological information. From the investigation of the data together with seismologic and geological-geophysical material, as a consequence, comes the conclusion of estimation of the potential seismicity of the neotectonic zone and individual morphostructures -- the most important element of seismotectonic analysis. Here the paleoseismodislocations depicting the maximum intensity of the earthquakes which occurred in one zone or another for the latest activation period and also the seismostatistical data and the results of their interpretation (activity map, K_{max}, and so on) are the most informative. This estimate of the epicentral zones of possible maximum earthquakes is presented on the potential seismicity map.[1]

On these maps on the neotectonic and, above all, seismotectonic level the investigated territory of Eastern Siberia encompasses the two large regions of different types -- to a significant degree the activated southern part of the Siberian Cenozoic platform and the epiplatform orogenic belt. The neotectonic and seismotectonic movements in them appeared differently and, along with the other geodynamic peculiarities gave rise to the specific nature of the manifestation of the earthquakes. Accordingly, four regions are isolated on the seismotectonic map: 1) stable and marginal activated zones of the platform; 2) the Baykalo-Stanovoy region of intense vault-block and riftogenic movements; 3) the Transbaykal block-wave zone and 4) the belt of morphostructures transitional between the second and third regions.

For certain large regions of the mountain belts of Eastern Siberia the seismogeological and seismostatistical information is meager or in general missing. Most frequently this is the poorly or recently inhabited regions

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[1] It is matched with the seismic regionalization map.

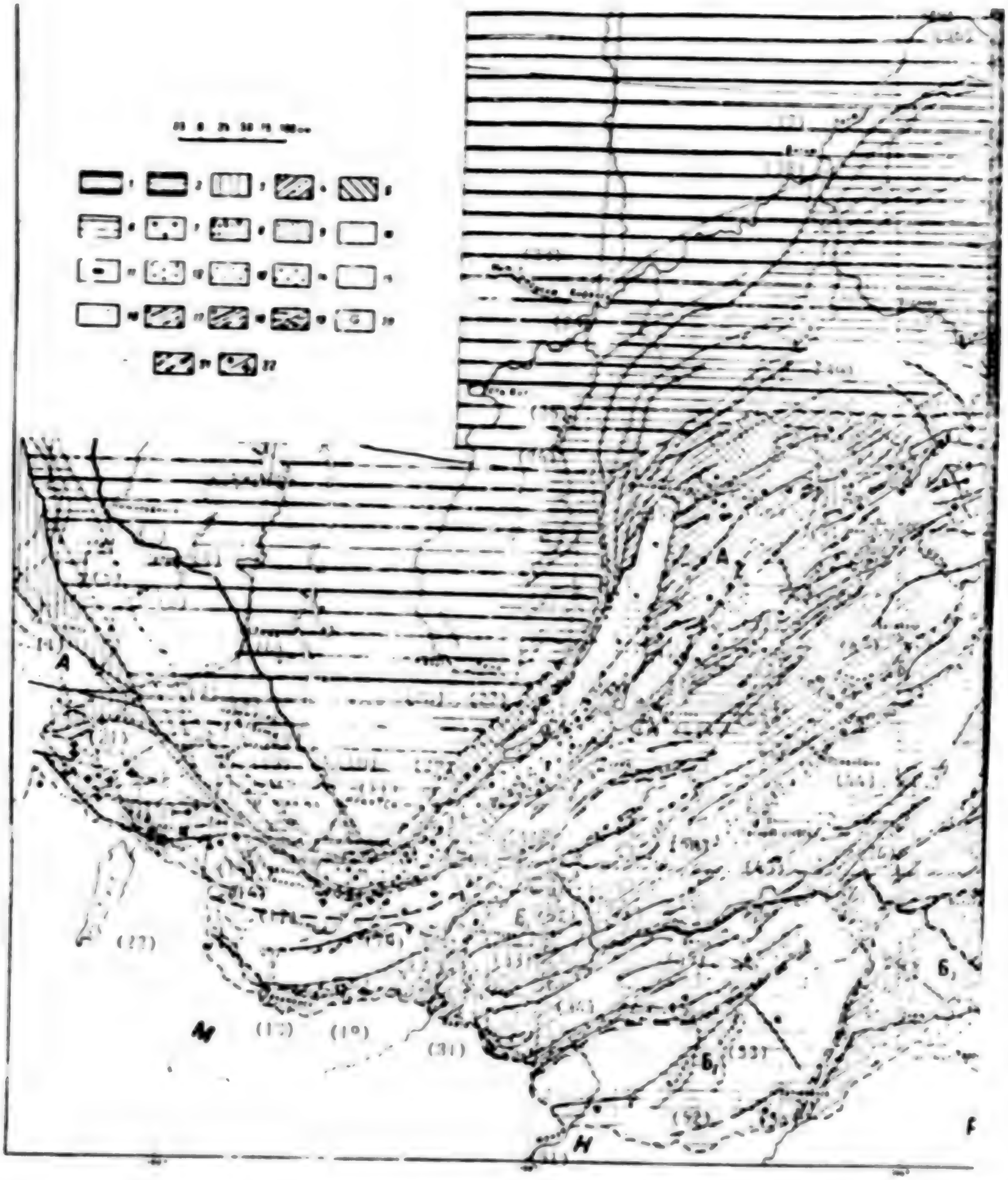

Figure 100. Seismotectonic map of Eastern Siberia. Compited by A. D. Abalakov, M. G. Del'yanovich, V. M. Zhilkin, R. A. Kurushin.

S. V. Lastochkin, V. V. Nikolayev, S. D. Khil'ko, V. S. Khomovskikh. Edited by V. P. Solonenko, 1973. [See legend and key, p 294]

[Legend and key to map, pp 292-293]:

Siberian Cenozoic platform: 1 -- stable regions, 2 -- edge parts encompassed by the Cenozoic activation; epiplatform Cenozoic orogenic belt: A -- Baykalo-Stanovoy zone of intense arch-block and riftogenic movements, B -- Transbaykal block-wave zone (B_1 -- Selenga-Vitim subzone of moderate differentiated movements, B_2 -- Khentey-Daurskaya subzone of intense arch uplift, B_3 -- eastern Transbaykal subzone of weakly differentiated movements); positive morphostructures: 3 -- block, 4 -- arch-block (A -- in zone A, B -- in zone B), 5 -- arch-fault, 6 -- arch, 7 -- interbasin and intrabasin commissures: negative morphostructures: 8-12 -- rift basins: 8 -- mature unloaded (a -- sections with sharp intrabasin differentiation of the foundation, b -- sections with weak interbasin differentiation of the foundation, c -- sections of maximum loading of the foundation), 9 -- mature loaded, 10 -- embryonic basins and satellite basins, 11 -- generating basin, 12 -- infantile basins; 13 -- subrift basins; 14 -- Transbaykal type basin; 15 -- fault basins of the unexplicit type: faults: 16 -- principal precenozoic, 17 -- active and Cenozoic (a -- established, b -- proposed): 18 -- deep (a -- established, b -- proposed). The relative notations is as follows: 19 -- relicts of troughs (a -- Mesozoic, b -- Tertiary), 20 -- Quaternary volcanoes, 21 -- boundaries (a -- Baykal rift system, b -- remaining zones and subzones), 22 -- epicenters of strong earthquakes: a -- with respect to seismostatistic ($M \geq 4$-1/2: $K \geq 12$), b -- with respect to paleoseismodislocations -- predominantly force 9 or more, $M \geq 6$-1/2.

Key:
1 -- Alygdzher; 2 -- Iya; 3 -- Nizhneudinsk; 4 -- Tulun; 5 -- Uda;
6 -- Zita; 7 -- Oka; 8 -- Cheretkhovo; 9 -- Bol. Belaya; 10 -- Angara;
11 -- Irkutsk; 12 -- Kitoy; 13 -- Mal Bedova; 14 -- Irkut; 15 -- Slyudyanka; 16 -- Baykal'sk; 17 -- Snezhna; 18 -- Zakamensk; 19 -- Dzhida;
20 -- Mondy; 21 -- Orlik; 22 -- Lake Khubsugul; 23 -- Lower Tunguska;
24 -- Kirensk; 25 -- Ust'-Kut; 26 -- Kirenga; 27 -- Lena: 28 -- Kachug;
29 -- Yelantsy; 30 -- Selenga; 31 -- Selenginsk; 32 -- Ulan-Ude;
33 -- Gusinoozerek; 34 -- Khilok; 35 -- Nizhneangarsk; 36 -- Lensk;
37 -- Lena; 38 -- Vitim; 39 -- Mama; 40 -- Upper Angara; 41 -- Uakit;
42 -- Bagdarin; 43 -- Mamat; 44 -- Romanovka; 45 -- Sosnovo-Ozersk;
46 -- Kutora; 47 -- Lake Baykal; 48 -- Barguzin; 49 -- Turka; 50 -- Uda;
51 -- Menza; 52 -- Chikoy; 53 -- Ingoda; 54 -- Chapcheranga;
55 -- Khilok; 56 -- Chita; 57 -- Bodaybo; 58 -- Vitim; 59 -- Lake Oron;
60 -- Nelyaty; 61 -- Chara; 62 -- Middle Kalar; 63 -- Vitim; 64 -- Karenga;
65 -- Bukachacha; 66 -- Shilka; 67 -- Nerchinsk; 68 -- Ingoda; 69 -- Onon;
70 -- Lake Barut-Torei; 71 -- Borzya; 72 -- Argun'; 73 --Gornyy-Zerentuy;
74 -- Amur; 75 -- Mogocha; 76 -- Tulik; 77 -- Olekma; 78 --Olekminsk
79 -- Temnik; 80 -- Gazimur ; 81 -- Kyakhta; 82 -- Tokko; 83 -- Andan;
84 -- Chara; 85 -- Ust'-Nyukzha.

with general seismic potential not exceeding force 8 (for example, the greater part of Transbaykal, the Baykal-Patomskoye Highlands). In such cases, at least for a qualitative estimate of the potential seismicity of the specific morphostructure, an estimate of the vertical tectonic movements is used (in combination with other data). For this purpose, by the corresponding procedure (Gzovskiy, et al., 1959; Gzovskiy, 1963) with certain alterations (Lastochkin, 1972) a map of the velocity gradients of the vertical tectonic movements with the mountain belt of Eastern Siberia was constructed (see Fig 101). In connection with the divergence of opinions noted in recent years with respect to the problem of the "relief-seismicity" ratio, it is necessary to give some explanations.

The values of the gradients for the different areas fluctuate from $5\cdot10^{-10}$ to $1\cdot10^{-8}$ $years^{-1}$ or more. The maximum values of them are characteristic of the Baykal-Stanovoy Highland with intense vault-block and riftogenic movements, the middle values, for the western and central parts of Transbaykal block-wave zone, and low values for the eastern part of the latter and the marginal zones of activation of the Siberian platform. The intrazonal ratio of the seismicity and magnitude of the velocity gradients of the vertical tectonic movements is exhibited far from always far from everywhere, and at times is contradictory. This indicates that the correlation between the seismicity and the relief exists not only in the most general form on the scale of at least the young mountain belts where mechanically imperfect articulation of the mobile (predominantly block) morphostructures is exhibited through the sharply differentiated and contrasted relief.

Thus, between the seismicity and relief (and, consequently, the velocity gradients of the vertical tectonic movements) in general form there must be as simple a correlation as exists between the latest tectonics and the relief on the whole. However, the seismotectonically similar relations can be expressed for regions of stable tectonic regimes. If the tectonic conditions change significantly in the modern age (for example, on the flanks of the rift zone), then the ratio of the level of modern seismicity and the velocity gradients of the vertical tectonic movements will be anomalous. Therefore the application of the "gradients" as the seismicity level index separated from the other seismotectonic criteria can lead to invalid representations of seismic potential of specific morphostructures and to serious errors during seismic regionalization. This pertains not only to the seismically active areas of Eastern Siberia. Many researchers (Petrushevskiy, 1960, 1964, 1969; Florensov, 1961, 1965; Florensov, et al., 1964; Solonenko, 1960c, 1965), and in recent times the authors of the method themselves when considering the problem of the "relief-seismicity" ratio have warned against exaggeration of this relation, especially when estimating the seismicity of the specific sections. Without going into a detailed discussion of the neotectonic history of the development of the mountain belt of Eastern Siberia which has already been the subject of broad discussion and was investigated in the well-known papers (Pavlovskiy, 1948b; Florensov, 1960a, 1968; ACTIVE TECTONICS..., 1966; SEISMOTECTONICS..., 1968; Lamakin, 1968; and so on), let us proceed to the seismotectonic analysis of the specific elements of the morphostructure of this territory.

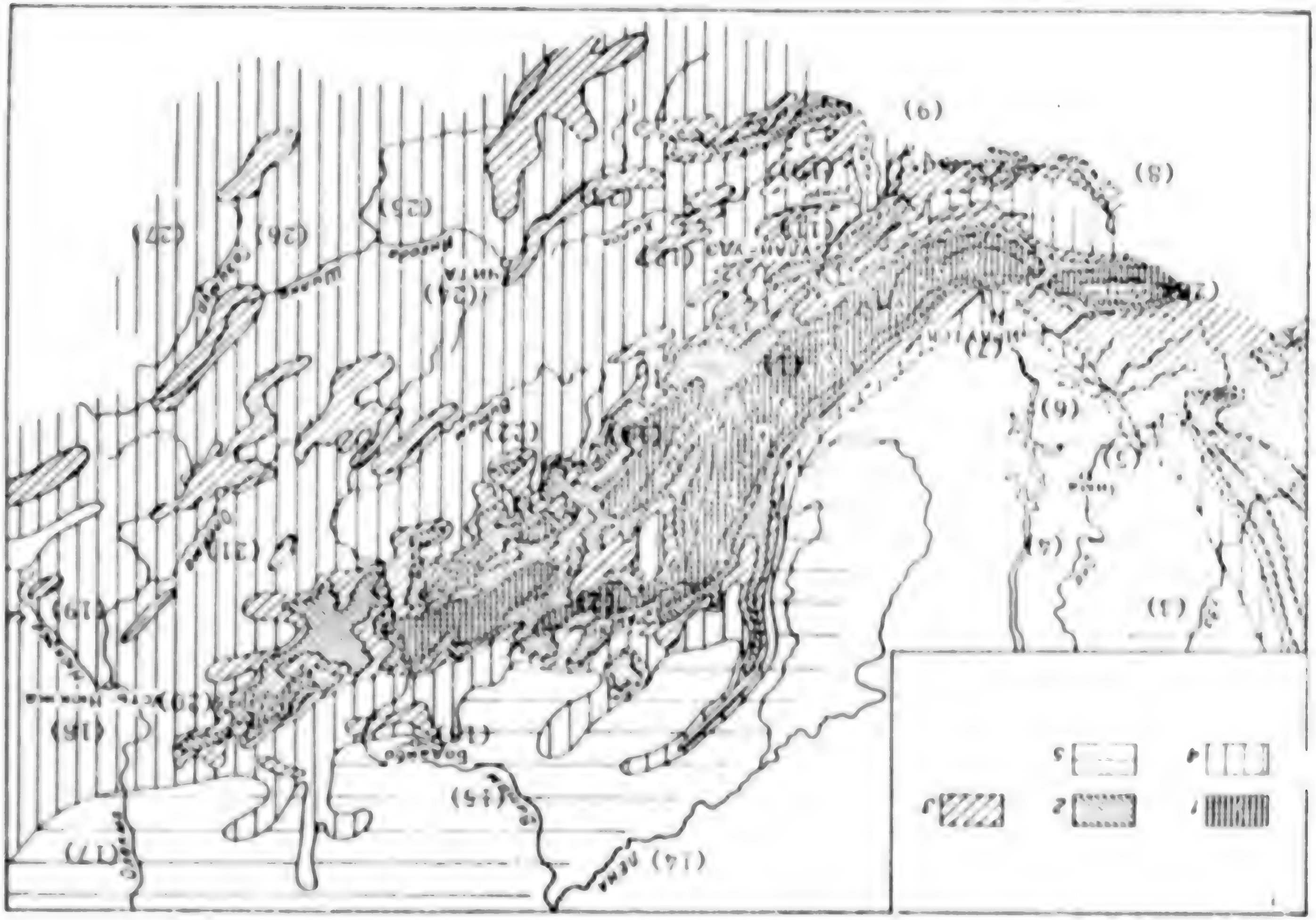

Figure 101. Map of the lowest values of the velocity gradients of the vertical tectonic movemen s in the territory of Eastern Siberia (for 10^7 years). Compiled by S. Lastochkin, R. Kurushin, 1973

1 -- to $(0.6-1)10^{-8}$ $years^{-1}$ are more; 2 -- to $(4-6)10^{-9}$ $years^{-1}$; 3 -- to $(2-4)10^{-9}$ $years^{-1}$; 4 -- to $(0.5-2)10^{-9}$ $years^{-1}$; 5 -- less than $(5)10^{-10}$ $years^{-1}$.

[See key on p 297]

[Key to Fig 101, p 296]:

1 -- Lake Baykal; 2 -- Upper Angara; 3 -- Uda; 4 -- Oka; 5 -- Zita;
6 -- Belaya; 7 -- Irkutsk; 8 -- Dzhida; 9 -- Chikoy; 10 -- Tugnuy;
11 -- Selenga; 12 -- Ulan-Ude; 13 -- Barguzin; 14 -- Lena; 15 -- Vitim;
16 -- Bodaybo; 17 -- Olekma; 18 -- Ust'-Nyukzha; 19 -- Nyukzha;
20 -- Chara; 21 -- Olekma; 22 -- Vitim; 23 -- Khilok; 24 -- Chita;
25 -- Ingoda; 26 -- Shilka; 27 -- Gazimur; 28. Irkut.

Siberian Cenozoic Platform

In the investigated territory of Eastern Siberia the platform region occupied a subordinate position, entering into it only as its own marginal, predominantly activated part. In the south and southeast it is bordered by the Baykal-Stanovoy orogenic belt from which it is sharply distinguished by low velocity gradients of the vertical tectonic movements ($5 \cdot 10^{-10}$ to $2 \cdot 10^{-9}$ years^{-1}). However, the Cenozoic tectogenesis has been manifested here in the form of gently sloping bending deformations. As Yu. V. Pavlovskiy (1948a, b) and N. A. Logachev, et al. (1964) have demonstrated, in the Cenozoic sediments of the marginal part of the platform signs of folding are noted -- predominantly flat synclinals with step angles of the limbs to 10°. The total stratigraphic thickness of the Cenozoic deposits reaches 500 meters (the Pre-Baykal trough).

The Baykal-Stanovoy orogenic belt has had significant influence on the marginal zone of the Siberian platform which was reflected in its differentiation with the formation of the Cenozoic troughs and uplifts. Nevertheless, the latest dislocations with a break in continuity, which play the principal role in the development of the morphostructures of Baykal-Stanovoy zone lose significance here, and the bending deformations and flexures are acquiring a defining role.

The geological-geomorphological, neotectonic and seismotectonic peculiarities of the Siberian platform will permit isolation of a stable (internal) zone and a zone encompassed by the Cenozoic activation (marginal zone) in its territory.

Stable Region. The stable region of the Siberian Cenozoic platform around the periphery of the Irkutsk amphitheater is bounded by the marginal foothills uplifts and troughs. For this region the lowest ($< 5 \cdot 10^{-10}$ years^{-1}) gradients of the vertical tectonic movements, broad development of the preneogene planation surface, large cupola-like and swell type uplifts with large radius of curvature are characteristic.

The neotectonic structures of the stable region of the platform are in practice aseismic. In addition, the nonuniformity of the structure of the crystal foundation and the mantle of thick Mesozoic and Cenozoic sediments covering it cause a different degree of manifestation of the "transit" quakes. In the uplifted regions they are manifested more sharply than in

the large troughs with the thick mantle of Mesozoic and Cenozoic sediments (the Pre-Baykal trough).

The marginal parts encompassed by the Cenozoic activ 'ion are a transitional morphostructural element between the platform and orogenic structures and have seismotectonic features characteristic of both the former and the latter.

The absence of internal neotectonic differentiation and host glacial activation of the dislocations with a break in continuity, good maintenance of the pre-Neogenic planation surfaces and the development of smooth forms of the relief and also the low degree of seismic activity will permit consideration of these morphostructures close to platform. On the other hand, the increased rate of neotectonic movements and their gradients (to $2 \cdot 10^{-9}$ years^{-1}) reflected in the specific forms of the relief indicate the ge- ic relation of the marginal uplifts and troughs to the Baykal-Stanovoy orogenic belt. The latter is also confirmed by the local centers of weak earthquakes which indicates their seismogenerating role, in contrast to the stable platform structures. The examples of such development are the Peredovoy ridge, the Baykalo-Patomskoye Highland, the Aldan shield, the Predbaykal'skiy [Pre-Baykal] and Prisayanskiy [Sayan] troughs.

The distribution of the local earthquake centers in the marginal zones of the platform is subject to some law. Wherever the orogenic belt has a clear discontinuous boundary (the Prisayanskiy section) or the Cenozoic troughs (Predbaykal'skiy) are directly adjacent to it, the activated zone of the platform usually has narrow (50-100 km) width, and the density of the epicenters decreases sharply in the direction of the platform. Wherever the marginal parts of the platform do not have clear boundaries, the density of the epicenters drops gradually on going away from the orogenic belt, and the width of such zones reaches 300 km (Baykalo-Patomskoye Highland), that is, is 3 to 6 times greater than in Prisayan'ye and Pribaykal'ye.

The marginal uplifts and troughs located under the effect of the intensive development of the Baykalo-Stanovoy zone of the arch-block and riftogenic movements participate passively in this process. Nevertheless, the accumulation and release of the tectonic stresses occurs here. Consequently, the marginal uplifts and troughs have independent seismotectonic potential, and the earthquake centers with magnitude to 4-3/4 (to force 7) are possible within their limits.

Epiplatform Cenozoic Or-- nic Belt

Baykalo-Stanovaya Zone of Intense Arch-Block and Riftogenic Movements

The Baykalo-Stanovaya zone is a system of regularly oriented linear morphtectonic elements which taken together make up a large arch-uplift framing the Siberian platform on the south. This latest first-order megastructure extends in the investigated boundaries from the mountain structures of Eastern Sayan to the Western part of the Stanovoy ridge a distance of

about 2000 km, with an average width of 150-200 km. Over the almost entire extent the axial part of the arch-uplift is fragmentally made up of the Baykal type basins, longitudinally and transversely differentiating it into the neotectonic structures of higher orders. In the majority of cases the latter correspond to the basic orographic element of the territory -- the mountain ridges and the intermontaine basins.

The basis for the morphostructural division of the Baykalo-Stanovoy zone is the concepts of geotexture, morphostructure and morphosculpture of the earth's surface developed by I. P. Gerasimov (1946) and deepened by Yu. A. Meshcheryakov (1965); Gerasimov, Meshcheryakov, 1967), N. A. Florensov (1960a, 1964), N. V. Dumitrashko, et al., 1969). In seismotectonic respects for us the most important are the morphostructures which are genetically the only complexes of tectonic-orographic elements created by the endogenic processes in the neotectonic stage of development.

The Cenozoic sedimentation cycle in which the history of formation of the morphostructures of the Baykalo-Stanovoy zone is imprinted is separated from the Mesozoic in time and, in part, in space. The regional break in sediment accumulation encompasses the Upper Cretaceous and the Paleogene.[1] During this period a thick (to 80 meters) weathering crust was formed which covers the weakly dismembered preneogene surface.

The territory of the high mountain belt of Eastern Siberia was, at the end of the Tertiary to the beginning of the Quaternary, subjected to intense tectonic effects, basically transforming its internal structure and relief (Logachev, 1958; Florensov, 1960a). The revolutionary period of the development of the modern mountainous terrain with its geological-geomorphological and hypsometric contrasts was preceded by a longer (Paleogene to early Neogene) evolutionary phase of development. In the Eocene-Oligocene, a transition was noted from the stable state to the slack-mobile tectonic regime (Logachev, 1968). The modern basins, in the majority of cases, then were shallow-water sedimentation basins. The relative rises of the sides of the basins above their bottoms were hardly more than 500 meters (Logachev, 1968). The area had at that time a slightly undulating, quiet relief. Judging by the thickness of the late Paleogene-Miocene coal-bearing sediments, the bending of the bottoms of the basins in this period, reached, in the final analysis, 1-3 km. However, this submersion obviously was compensated for at the same time by accumulation of sediments and large unloaded bodies of water, and there was no similarity to the modern Baykal basin (Logachev, 1958; Florensov, 1968).

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[1]The terrigenic-effusive suite up to 60 meters thick of provisionally Paleogene age has recently been isolated in the Tunkinskaya basin (Mazilov, et al., 1972). N. A. Logachev (1968) admits the possibility of the existence of the Cretaceous-Paleogene deposit in the basins of the Baykal system at depths of more than 3000 meters.

The basic changes in the tectonic life of the region occurred at the end of the Tertiary to the beginning of the Quaternary (Florensov, 1965). The powerful process of beginning mountain formation led to a sharp tectonic differentiation of the relief. Against the background of the archogenic bulging of the territory, the morphostructures of various orders were formed and gradually acquired the modern outlines (the arch-ridges and their antipodal troughs). The mechanical differentiation of the sediments across the basins reflects intensive growth of their mountain framing (Logachev, 1968), reaching its maximum in the vicinity of the modern Baykal mountain region. The development of the rift zone in the Late Pliocene and Anthropogene occurred under the conditions of the suppression of the early plastic forms by more and more active discontinuous deformations (Florensov, 1968).

In general outlines, the scale and contrast of the Cenozoic movements can be characterized by the following facts. The continental deposits of the Mesozoic detected in the Baykalo-Stanovoy zone occur in the form of disconnected fields on various hypsometric levels. On the one hand, they are covered by drilling in the Selenga River delta at a depth of more than 1500 meters, and on the other hand they are encountered at altitudes to 2000 meters or more in the Tunkinskiy, Udokan and Kodar ridges. Genetically these deposits have not been connected at all with the modern relief. The Neogenic sediments have been found on bald peaks 2000 to 2500 meters above sea level (the Khamar-Daban ridge, the Kitoyskiye and Tunkinskiye bald peaks). Here they occur horizontally or are slightly inclined (Florensov, 1960). Analogous deposits of the intermontane troughs occur, according to the drilling and geophysical data, at 2000 to 2800 meters below the earth's surface (1500 to 2300 meters below sea level). Moreover, it is not excluded that the foot of the Tertiary deposits in the Baykal basin occurs almost at 6000 to 7000 meters below sea level (Zorin, 1971; Vetrov, 1968; Bulmasov, 1968), and according to the magnetotelluric sounding data, even 10,000 meters below sea level. In this case the magnitude of the vertical displacement of the separated sections of the Tertiary peneplain reaches 12 km. These data indicate the powerful differentiated movements of the post-Neogene time leading to basic rearrangement of the earth's surface and the occurrence of high-contrast, Quaternary relief of the mountain belt of Eastern Siberia (Florensov, 1960; Logachev, et al., 1974).

On the whole, the latest structure of the Baykalo-Stanovoy zone is defined by the complex interaction of the bending and discontinuous deformations of the earth's crust. With respect to nature of manifestation and direction of the neotectonic movements, they are broken down into two basic groups -- positive (uplift) and negative (subsidences) of the morphostructure. Both were formed, judging by the existing sections of the Cenozoic sediments, simultaneously. The amplitudes of the absolute descending movements are comparable or significantly exceed the amplitudes of the ascending movements. The latter is characteristic of the Baykal basin, in individual parts of which the ascending movements account for no more than one-third of the total amplitude of the vertical neotectonic movements. On the flanks

of the Baykal-Stanovoy zone -- in Eastern Sayan and on the Stanovoy ridge -- relatively poorly differentiated absolute uplifts predominate (positive morphostructures predominate sharply).

Thus, the principal role in the neotectonic and seismotectonic development of the Baykalo-Stanovoy zone of intensive arch-block and riftogenic movements goes to the positive and negative morphostructures making up a complex evolutionary series and the zones of activated faults -- the principal seismically active lineaments.

Positive Morphostructures. With respect to predominance of one type of deformation or another, the uplifts are subdivided into block, arch-block fault-arch and arch uplifts.[1] The boundaries between them are frequently provisional to a known degree, and they are often characterized by gradual transitions.

The fault-arched uplifts are a specific set of tectonic-orographic elements framing the Baykal rift zone on the Siberian platform side. This boundary position of the fault-arch uplifts determines the peculiarities of their internal neotectonic structure and seismicity.

The most characteristic example of this morphostructure is the Primorskiy and the Baykal ridges framing the Lake Baykal basinon the northwest. Structurally and morphologically they are a single uplift about 600 km long and from 15 to 60 km wide. The absolute elevations of the upper surface increase nonuniformly from the southwest to the northeast from 1000 to 2400 meters. On the Baykal side the uplift is controlled by just as extended subparallel systems of normal faults and strike-slip faults active in the Cenozoic and entering into the zone of the powerful long-lived Obruchevskiy fault. They cut the lake slope of the morphostructure into narrow linear tectonic blocks submerging by steps into the basin. A characteristic peculiarity of the fractures outlining the strike-slip faulted uplift on the basin side is the maximum amplitudes of total vertical neotectonic movements for the rift zone. This is indicated by the difference in elevations of the basement of the basin and the upper surface of its mountain frame, reaching 8000 to 8500 meters in the narrow belt on the west side (Zorin, 1971).

On the platform side the bending nature of the deformation of the initial surface is clearly exhibited which leads to deformation of the northwest limb of the strike-slip faulted uplift. Here the ground surface gradually rises to the axial line of the structure closest to the shore of the lake, there are no large neotectonic sutures, and no modern activation of the dislocations with a break in continuity is noted. The transition from

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[1]The arched uplifts, as atypical of the investigated zone, are characterized in the section on "Transitional Structures."

platform to ridge structures frequently is reflected by the formation of the latest flexures at the present time in practice aseismic.

Thus, in the transverse cross section the uplifts of the Primorskiy and Baykal ridges have the nature of a narrow, internally weakly differentiated limb of the arch separated in its axial part by a system of large-amplitude young fractures. The latter almost everywhere bear traces of Holocene seismogenic rejuvenation. A more blurred picture is observed on the northern extrem ty of Baykal and in the Northern Baykal Highland where virgation, gradual damping of the dislocations of the break in continuity and significant internal differentiation of the morphostructure are noted. This section corresponds more to the other morphogenic type -- the fault-block uplift.

The analogous fault-arch morphostructures frame the large mature basins of the rift zone of the Stanovoy Highland on the northwest and north -- the Upper Angara, Muya and Chara. Their morphological characteristic consists in significantly greater width of the external platform limbs which can be explained by the fact that here the fault-arch uplifts plastically become a weak marginal part of the platform uplifted in the Cenozoic. Accordingly, the northern boundary of the rift zone is becoming even more shaded and undefined.

The sharp asymmetry of the fault-arch uplits obviously determines the different modern seismicity of their platform and prerift parts -- from minimum to forces 8-9. In addition, it is possible to note the variation in the degree of seismic activity and with respect to strike of the morphostructures. In particular, it decreases in the northern part of the Baykal ridge where, as has already been stated, virgation and damping of the morphostructural elements are noted.

In the zones of articulation with the negative structures, the level of the potential seismicity of the fault-arched uplifts according to the seismogeological data can reach force 11-12 in the Baykal frame and force 10 in the frame of the Stanovoy Highland basins. The seismic danger of the internal field of the uplift is determined basically by the transit quakes from the fracture centers of the earthquakes.

The block uplifts are essentially horsts of different magnitude, most frequently one-way, located along the axial part of the rift zone -- in the belt of maximum differentiated and contrasted neotectonic and modern movements of the earth's crust.

The internal field of the block uplifts is most frequently not differentiated or it is slightly differentiated. Here, in practice there are no young or rejuvenated faults or the higher order morphostructural elements connected with them or seismogenic structures. However, in many cases the principal zones of the fractures controlling the horsts are accompanied by the feathering transverse or diagonal and longitudinal (accompanying) fractures.

The negative structures are sometimes genetically connected with them -- as generating and embryonic bases of the Baykal type and the paleoseismo-dislocations reflecting the youngest (Holocene) differentiation and, probably inversion of the radial tectonic movements in the axial strip of the rift zone. As examples of such uplifts we can use the northeastern part of the Yuzhno-Muyskiy [Souther Muya] ridge (the interfluve of the Syul'ban and Konda), the Dovachanskiy block in the vicinity of the Muya-Chara inter-basin commissure and the Svyatoy Nos Peninsula (the diagonal commissure inside the Lake Baykal basin).

The width of the transition zone between the block uplifts and the negative morphostructures in contact with them is minimal. Morphologically, they are represented by steeply inclined oblique plains bounded at the rear by tectonic sutures. Usually these are extended (to 100-200 km) fractures having a long history of development and significant (to 1.5-2 km) amplitudes of vertical displacement caused by differently directed movements of the horsts and the basins connected with them. The numerous epicenters of both strong and weak earthquakes and especially paleoseismogenic structures stretch spatially to these zones. The bending deformations here are in practice absent, and the stress relief is transformed only into discontinuous shifts of the monolithic blocks along the strike-slip faults bounding them.

On the whole the potential seismicity of the block uplifts appears to be the highest of all of the positive mophostructures of the Baykal-Stanovoy zone. It is determined primarily by the coordination of morphostructures (the most tectonically active and sharply differentiated parts of the rift zone which causes maximum mobility of the entire body of the positive structure with sharply contrasting movements along the faults bounding it. The expected maximum force of the earthquakes within their limits can reach force 8-9 with local increases (as a result of complication of the uplift by feathering and accompanying fractures) to force 10. The potential activity of the block structures participating in the framing of the large mature basins of the Baykal type (the Tunkinskiye bald peaks, the southern half of the Barguzin ridge) and also making up individual uplifts in the Eastern Sayan part of the zone appears lower (force 7-8) on the basis of their significant monolithic nature and much lower modern seismic activity.

The arch-block uplifts in the Baykal-Stanovoy zone are wider. Primarily, they frame, together with the arched morphostructures, the system of rift basins from the direction of the Transbaykal block-wave zone. The south-eastern or southern limbs of these uplifts are in many cases simultaneously the sides of negative morphostructures of the subrift type bearing the features of basins of both zones (see below).

In the formation and evolution of the arch-block uplifts an equivalent role is played both by the bending deformations and the discontinuous deformations, which is well illustrated by the most typical morphostructure of the Udokan ridge bordering the Chara and the Tokka rift basins from the south and southeast (ACTIVE TECTONICS..., 1966).

The widespread nature of the morphostructural elements of higher orders, both negative and positive, in the Udokan ridge indicates complex differentiation of the radial tectonic movements during the formation of the arch-block uplifts, reaching the culmination point at its development (in the sense of the maximum accumulation of arch stress) in the Holocene. Therefore the internal fracture zones of the morphostructures carry traces of the grand seismic disasters of the recent past -- the China-Vakatskaya, Kemen, and Medved' structures. The high seismic potential of the morphostructure as a whole is determined by them.

The arch-block uplifts in the other parts of the Baykal-Stanovoy zone are distinguished from the Udokan by the degree of tectonic differentiation of their internal fields. Thus, for example, the morphostructure of the northern half of the Barguzin ridge is differentiated quite poorly and at that, primarily on the Baykal basin side. The degree of internal differentiation also of the western part of the arch-block uplift of the Stanovoy ridge is approximately the same. At the same time obviously gradual transitions are noted from the arch-block to arch morphostructures.

The level of modern seismic activity of the arch-block uplifts is comparatively low with the exception of the proposed epicenter of the force 11 earthquake on 2 February 1725 where quakes up to 14th energy class are known. The numerous epicenters of the weak earthquakes are distributed more or less uniformly, with greatest concentration in the zones of embryonic basins and the most important activated faults controlling the uplifts and the partial higher order structures inside them.

The intrabasin and interbasin commissures are blocked projections of the crystalline basement of the rift zone reflecting the internal differentiation of the negative morphostructures and separating them from each other. The classification of the commissures in one type or another frequently is difficult, for in the majority of cases the rift basins form geomorphologically united, extended structures, in which the interbasin commissures differ little from intrabasin. For example, the linear zone of basins and the commissures of the Tunkinsko-Yuzhnobaykal'sko-Barguzinsaya system separating them is this type of zone (see Fig 102).

An essentially different picture is observed in the northeastern (Baykal-Chara) segment of the rift zone where, along with the linear systems, an echelon type arrangement of the basins is traced. The large mature Baykal type basins do not have a direct structural or morphological relation to each other here. They are separated by broad sections of the rift zone broken up to the maximum, in the makeup of which the block uplifts predominate (Fig 103). The latter constitute a direct continuation and result of the internal differentiation of the positive morphostructures making up the limbs of the rift zone with which they have comparable amplitudes of uplift. These sections can be considered as interbasin mountainous commissures (Upper Angara-Muya, Muya-Chara, and, possibly, Barguzino-Muya).

The intrabasin commissures are characteristic morphostructural elements of the majority of the basins from embryonic to mature. They have much less altitude than the surrounding uplifts, and they usually are blocks of the basement, relatively stable or experiencing retarded subsidence. With respect to general orientation of the basins the commissures can be arranged longitudinally, transversely and diagonally, which is predetermined by the conditions of their formation and the nature of the bordering young fractures. The diagonal and transverse commissures arose as a result of gradual longitudinal merging of the adjacent basins into a single, large negative neotectonic structure, and the longitudinal commissures, as a result of lateral merging of the two parallel basins.

The seismotectonic potential of the intrabasin and interbasin commissures is different in the different parts of the rift zone. It is the highest both with respect to seismogeological and instrument seismological data in the rift zone of the Stanovoy Highland (ACTIVE TECTONICS..., 1966). The majority of paleoseismogenic structures and epicenters of both strong and weak earthquakes have been coordinated with the commissures. The modern seismic activity of the regions of interbasin commissures is approximately three times the average for the Baykal rift zone.

In the Central and Southwestern Baykal region the level of seismicity of the commissures is on the whole reduced, although there are extreme cases -- the highest Holocene and modern activity of the Svyatoy Nos block (Abalakov, 1973, 1974) entering into the composition of the diagonal commissure separating the basins of Southern and Northern Baykal and almost complete tectonic passiveness of the commissure between the basins of Southern Baykal and Tunkinskiye.[1]

Negative Morphostructures. In the Baykal-Stanovoy zone of the epiplatform orogenic belt the above-described positive morphostructures are genetically and spatially closely connected with the narrow linearly expended graben-like basins. In accordance with the seismotectonic classification of V. P. Solonenko (1968) these negative morphostructures form a single evolutionary series: generating -- embryonic -- mature (monostructural and polystructural) -- fading (or infantile) (Fig 104). The developing morphostructures of this series determine the seismic potential of both the entire territory as a whole and its individual parts. Therefore it is expedient to present a brief characteristic of the standard negative morphostructures considering the results of the latest studies performed in recent years (Logachev, 1968; Zorin, 1971; Shmotov, 1972; Solonenko, V., et al., 1971; SEISMOTECTONICS..., 1968, 1975a, b; Mazilov, et al., 1972; Ruzhich, 1972; Sherman, et al., 1973; Puzyrev, et al., 1973).

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[1] The seismic passiveness of this commissure during at least the last two to three centuries still remains a riddle: such powerful and active faults as the Cherskiy, Obruchev, Tunkinskiy and Main Sayan converge in its vicinity.

The generating basins are formed on the slopes and in apical parts of the series of positive morphostructures.

This type of basin includes the highland graben-troughs of the seismogenic structures: Kitoyskaya, Babkhi, Snezhnaya, Tankhoyskaya, Primorskaya, Dovachan and Baronki. Some of them possibly occurred at the end of the Pleistocene, but the most intensive development came in the Holocene and in the modern epoch. The extent of the highland seismogenic grabens fluctuates from 0.6 to 12 km, the width and the depth fluctuate from tens to hundreds of meters. The faults bounding the grabens follow the ancient fractures or occurred in a primarily integral crystalline substrate. However, in both cases they are traces of catastrophic earthquakes with an intensity of up to force 10-11. The bottoms of the grabens -- fragments of plateau and sharp peaked mountain tops -- are wedged inside the ridges experiencing tension. The sediment accumulation in the generated basins occurs in the initial stage. The thickness of the sediments does not exceed the first tens of meters. The brightest representative of the generated basins is the central graven of the seismogenic structure of Dovachan. Its extent is 12 km, its width is 0.8 km and its depth is up to 100 meters. The high seismic potential of this basin is proved not only by the presence of paleo-seismodislocations, but also the extraordinarily high modern seismic activity and also the overstressed state of the rock. The latter gives rise to a high recurrence rate of rock slides here. One of them, which occurred on 29 July 1961, instantaneously encompassed the front of the slope about 2.5 km long. In the case of the landslip of 27 July 1962, the crushing of the rock occurred independently of the systems of separation joints developed in them (ACTIVE TECTONICS..., 1966; Solonenko, V., 1968c).

In the vicinity of the generated basins, earthquakes with M to 7-3/4 to 8-1/4 (force 10-11) are possible.

The embryonic basins occurred obviously in the lower or middle Pleistocene. The length of such basins is the first tens of kilometers, the width is up to 6 km, and the thickness of the sediments accumulated in them is 300-400 m. These morphostructures can be classified as grabens, one-way grabens and graben-like synclinals. The fracture boundaries of the majority of them have explicit signs of seismogenic rejuvenation accompanied by underground shocks of intensities from force 9 to force 10-11.

In the Baykal-Stanovoy zone there are a large number of embryonic basins that have been isolated. The most typical of them are the Mondy, Gremyachaya, Verkhneikatskaya, Kovoktiskaya, Tilishminskaya, Namarakitskaya, and Ignamakitskaya basins. In essence, they are morphologically basins of the Baykal type in miniature. In the more developed of them the block differentiation of the basement is manifested.

In the Baykalo-Stanovoy zone a large number of embryonic basins have been isolated. The most typical of them are the Mondinskaya [Mondy], Gremyachaya, the Verkhneikatskaya, Kovoktinskaya, and Tilishminskaya, Namarakitskaya, Ignamakitskaya. Essentially morphologically they are mature basins of the Baykal type in miniature. In the more developed of them the block differentiation of the basement is freely exhibited.

In the case of one-way grabens, the embryonic basins have either Baykal asymmetry or asymmetry that is the inverse of it.

The seismotectonic essence of the embryonic basins is expressed by the fact that in the zones of these negative morphostructures that are smaller in size, extraordinarily thick seismic stresses are generated. The seismogenic stress fields go beyond the limits of the basin area, as a result of which the feathering and accompanying discontinuous dislocations occur which, along with the main fault systems, have high seismic potential. The sign of active buildup of the embryonic basins is the seismogenic discontinuities going beyond the geomorphological outlines of these morphostructures. The embryonic basins breaking the arch-block uplifts and the crystalline commissures between the large negative morphostructures usually form chains extended along the large lineaments or located to the side of them. Many large paleoseismodislocations and epicenters of the strongest earthquakes (M=6.5-7.9) in the Stanovoy Highland extend to the areas of embryonic basins. One of them, the Namarakitskaya, participated in the generation of the strongest earthquake in the USSR in the last 65 years, the Muya earthquake of 27 June 1957 (M=7.9; I_0=force 10-11). In this case the bottom of the basin subsided by 5 to 6 meters and was shifted to the southwest; the Udokan ridge bordering the basin on the south was uplifted 1 to 1.5 meters and shifted to the northeast by 1 to 1.2 meters. The system of seismodislocations occurring along the faults delimiting these morphostructures had a total extent of about 30 km. The gaping of the fractures reached 8 to 10 and even 19 meters.

It is highly indicative that the seismogenerating stresses in the embryonic basins extend to greater depths (to 40 km or more) than on the average along the rift zone (the depth of the centers of the strong earthquakes is 20 ± 5 km, weak earthquakes, predominantly about 10 km), which is established by the distribution of the hypocenters of the aftershocks (ACTIVE TECTONICS..., 1966).

In the investigated territory, the regions of the embryonic basins and morphostructures with generated basins have the highest seismic potential. According to the instrument and paleoseismogeological data, the epicenters of the earthquakes with M to 8 can be associated with them (I_0=force 10-11).

The mature basins constitute the basis for the Baykal rift system and are divided into two groups -- unloaded and loaded, or dry valley.

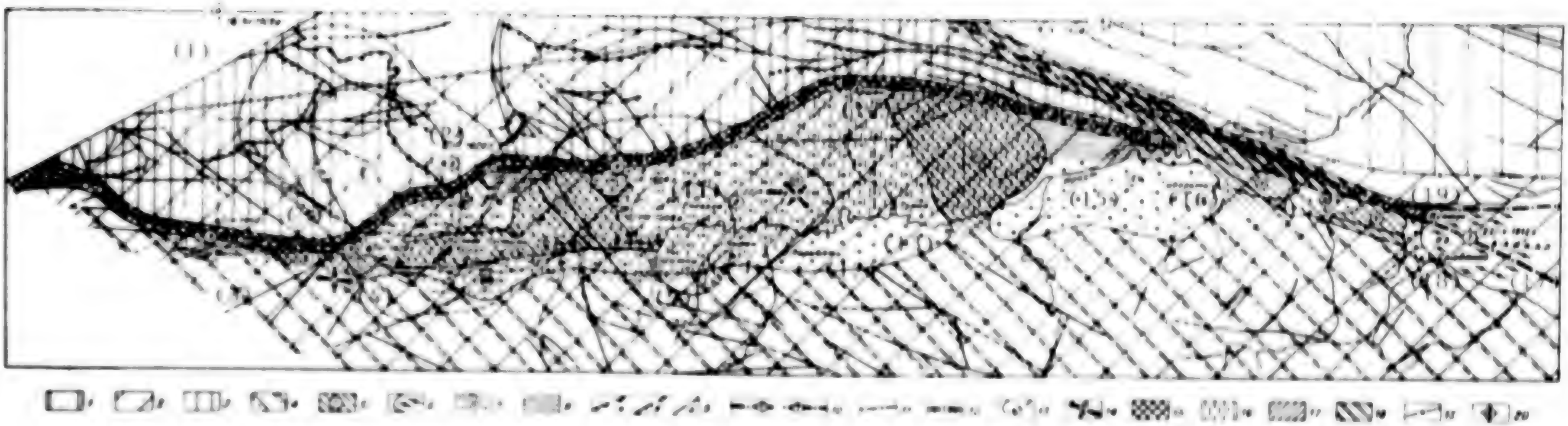

Figure 102. Seismotectonic map of the vicinity of the Tunkinskaya system of basins.
Compiled by V. Khromovskikh, V. Solonenko, V. Zhilkin.

1 -- marginal parts of the Siberian platform encompassed by Cenozoic activation; 2 -- Baykal rift zone; 3-5 -- positive morphostructures: I -- Khamar-Daban, II -- Nilovskaya, III -- Yelovskaya, IV -- Tibel'tinskaya, V -- Kultukskaya (zones of retarded uplift); VI-VII -- negative morphostructures (rift basins of the Baykal type); 6 -- unloaded basins with sharp intrabasin differentiation of the basement; 7 -- loaded basins; VI -- Mondy, VII -- Khoytogol'skaya, VIII -- Turanskaya, IX -- Tunkinskaya [Tunka], X -- Torskaya, XI -- Bystrinskaya [Byrstra]; 8 -- the intrabasin sections of the modern troughs connected with longitudinal faults; IX -- pre-Cenozoic faults: a -- overthrusts; b -- normal-thrust fault type, c -- other; 10 -- ancient fractures activated in the Cenozoic; T -- Tunkinskaya [Tunka], C -- main Sayanskiy [Sayan]; 11 -- Cenozoic fractures; 12 -- segments of fractures rejuvenated and occurring during earthquakes with an intensity of force 10 and paleoseismogenic structures: I -- Arshanskaya, II -- Torskaya; 13 -- seismic activity isolines (A_{10}); 14 -- maximum stresses in the earthquake centers: white arrows -- orientation of the compression axes, black arrows -- the same, tension; 15-18 -- potential seismicity (passable epicentral zones of maximum earthquakes), 15 -- M>7 (force 10 and more), 16 -- M=6-1/2-7 (force 9), 17 -- M=5-1/2-6-1/2 (force 8-9), 18 -- M=4-3/4-5-1/2 (force 7-8); 19 -- boundary of the Baykal rift zone; 20 -- epicenters of strong (M≥4-1/2) earthquakes with respect to seismostatistics.

[Key on p 309]

[Key to Fig 102, p 308]:

1 -- 18 December 1928; 2 -- 8 March 1820; 3 -- 4 September 1950;
4 --8 March 1829; 5 -- Monoy; 6 --Nileva Pustyn' Khutun;
7 -- Yelotv; 8 -- Shilka; 9 -- Kyren; 10 -- 19 August 1958; 11 -- Yengarga;
12 -- Kharibaty; 13 -- Tunka; 14 -- Arshan; 15 -- Irkut; 16 -- Tibel'ta;
17 -- Lake Baykal; 18 -- Slyudyanka; 19 -- Kultuk

The unloaded basins include the Lake Baykal basin which occupies the central place among the rift morphostructures. It is divided into two depressions -- Yuzhnobaykal'skya [Southern Baykal] and Severobaykal'skaya [Northern Baykal] -- correspondingly with sharply and weakly differentiated basements (see Fig 100). Obviously, the riftogenesis process began with the formation of its southern trough, then spreading to the northeast and west (Florensov, 1960a; Logachev, 1968) although some of the researcher consider the northern basin of Baykal more ancient than the southern one (Dmitriyev, Kolokol'tseva, 1970). The beginning of the rift formation in the vicinity of Southern Baykal is more probable inasmuch as the axis of the great neotectonic trough traced along the entire complex of structures and orographic signs from the southern edge of the Siberian platform deep into Central Asia runs here. This point of view is adhered to by the majority of researchers (Florensov, 1960a, 1961; Solov'yev, 1963; Logachev, 1968; SEISMOTECTONICS..., 1968).

The basic elements of the structure of the Baykal basin and one of the largest dislocations with a break in continuity are the Obruchevskiy fracture (Shcherbakov, 1951) and the Cherskiy fault which are described in the section on "Activated Faults."

The thickness of the lens of loose Cenozoic sedimenwts making up the Southern Baykal basin varies from 4 to 6 km, and in the frontal part of the Selenga River delta it increases to 8 km (Vetrov, 1968; Zorin, 1971). By the thicknesses of the Cenozoic sediments of the Southern Baykal basin[1] we can determine the sedimentation rate and also the rate of flexure of the bottom of the depression. The thickness of the Tertiary deposits in the vicinity of Tankhoya, according to the data of G. B. Pal'shin (1955) and N. A. Logachev (1968) is 1905 meters. However, somewhat to the west is the Solzanskaya depression which represents the next regular element in the system of Tankhoyskiye Cenozoic flexures. The maximum thickness of the older-shingle, supposedly Quaternary formations making it up is 500 meters (Solonenko, V., 1964a).[2] The Solzanskaya depression has great structural-tectonic similarity to the Proval Bay which, is associated, just as the depression, with the Cherskiy fault zone. The thickness of the Quaternary sediments in the Proval Bay exceeds 300 meters, and in the Ust'-Selenga

[1]The Northern Baykal basin is excluded from the calculations, inasmuch as the reliable thickness of the Quaternary deposits is known for it, and there are contradictory data about the age.

[2]According to the latest geophysical data, to 700 meters.

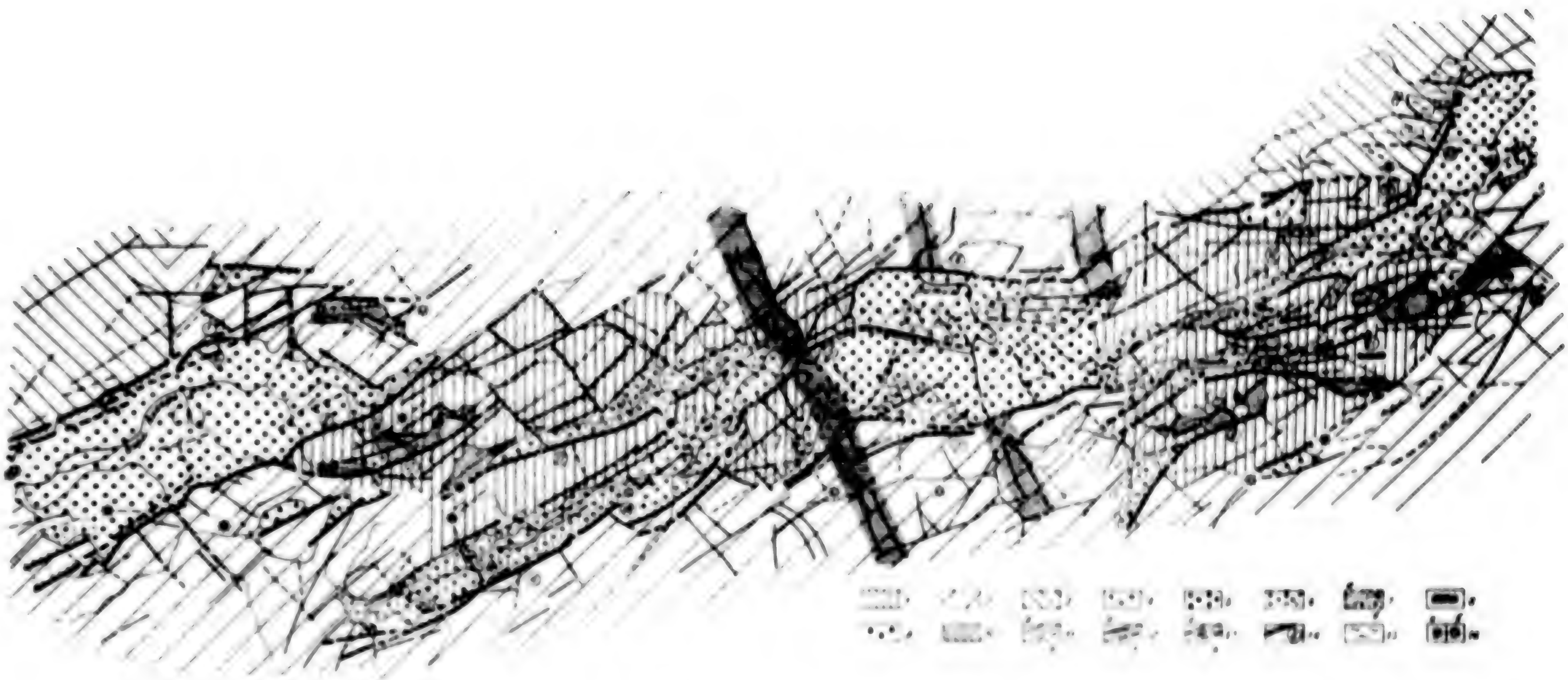

Figure 103. Seismotectonic structure of sections of the Stanovoy Highland zone between the mature loaded basins of the Baykal type. Compiled by R. Kurushin.

[See legend and key on p 311]

[Legend and key for Fig 103, p 310]:

1-4 -- Positive morphostructures: 1 -- block, 2 -- arch-block; 3 -- fault-arch, 4 -- relatively uplifted blocks of the basement (intrabasin and inter-basin crystalline commissures); 5-9 -- negative morphostructures (rift basins); 5 -- mature polystructural, 7 -- intermediate type between mature and embryonic (a) and satellite basins (b), 8 -- generating, 9 -- supposedly embryonic; 10-14 -- fractures (bergstrichs in the direction of the downthrown wall): 10 -- deep, 11 -- pre-Cenozoic (a- reliable,b -- proposed), 12 -- active in the Cenozoic (a - reliable,b - proposed), 13 -- riftogenic, seismogenerating, 14 -- sections of faults rejuvenated during earthquakes with intensity of force 9 or more, 15 -- relicts of the upper Mesozoic trough; 16 -- epicenters of strong (K.12) earthquakes (a -- established with a precision of a and b, b -- nonclassical).

Key:

1 -- Upper Angara; 2 -- Muyakan; 3 -- Vitim; 4 -- Mondy; 5 -- Syul'ban; 6 -- Chara; 7 -- Muya.

depression, about 500 meters (Zamarayev, Samsonov, 1959).[1] Let us remember that in the Tunka basin the thickness of the Pleistocene deposits is 400 to 500 meters. Consequently, for approximate calculations of the rates of flexure of the bottom of the Southern Baykal basin we are correct to take the thickness of the Quaternary sediments close to 500 meters for it. However, then the sedimentation rate in the Tertiary period (25 to 30 million years) is about 70 meters in 1 million years, and in the Quaternary period (1 million years) it is close to 400-500 meters. Consequently, the rate of subsidence of the crystalline bed of the basin increased by 6-7 times in the Anthropogene.

Combined with the other attributes this can serve as an explanation of the high seismicity of the Southern Baykal trough. However, the front of the neotectonic and seismotectonic processing of the crystalline substrate during the historic period encompasses not only the peripheral zones of the basin. It shifts in the direction of its mountain border and, in particular, to the north slope of the arched uplift of Khamar-Daban. In the last centuries and millenia the most intensive crushing of the crystalline substrate has taken place with the formation of inversion seismogenic structures genetically related to the force 10-11 earthquakes.

The northern basin of Baykal has been studied in less detail. Its basin is weakly differentiated. It is separated from the Southern Baykal depression by the uplift of the Academic ridge -- the underwater continuation of the

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[1] In the last paper by V. V. Samsonov and G. P. Ponomareva (1970) part of the upper Pliocene deposit section is included in this number.

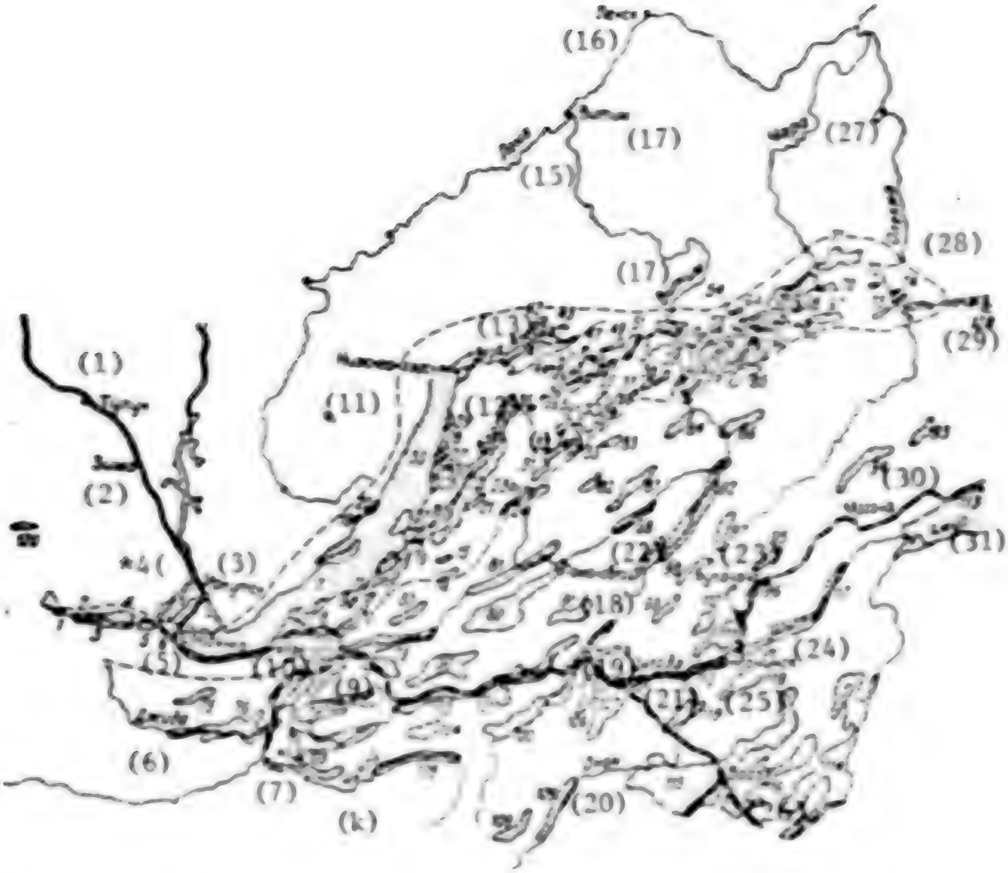

Figure 104. Schematic of the arrangement of the most important basins of the epiplatform orogenic belt of Eastern Siberia. The dotted line denotes the boundary of the Baykal rift zone. Compiled by R. Kurushin, S. Lastochkin.

1 -- Mondy; 2 -- Khoytogol'skaya; 3 -- Turanskaya; 4 -- Tunka; 5 -- Torskaya; 6 -- Bystra; 7 -- Baykal'skaya yuzhnaya [Southern Baykal]; 8 -- Selengino-Itantsinskaya [Selenga-Itantsa]; 9 -- Kolokskaya; 10 -- Itantsa; 11 -- Kotokel'sk ya; 12 -- Turkinskaya; 13 -- Maksimikhinskaya; 14 -- Verkhneturkinskaya; 15 --Yambuyskaya; 16 -- Ust'-Barguzinskaya; 17 -- Malochivyrkuyskaya; 18 -- Gremyachaya; 19 -- Ongurenskaya; 20 -- Kocherikovskaya; 21 -- Ulan-Burginskaya; 22 -- Barguzinskaya; 23 -- Verkhneikatskaya; 24 -- Vitimkanskaya; 25 -- Sosnovskaya; 26 -- Bol'sherechenskaya; 27 -- Yezovskaya; 28 -- Kaban'ye; 29 -- Shegnanda; 30 -- Baykal'skaya severnaya [Northern Baykal]; 31 -- Gorbylokskaya; 32 -- Tsipikanskaya; 33 -- Alakarskaya; 34 -- Tsipa-Bauntovskaya; 35 -- Amutskaya; 36 -- Turaki; 37 -- Kadalinskaya; 38 -- Bambukoyskaya; 39 -- Tilishminskaya; 40 -- Bamouyskaya; 41 -- Verkhneangarskaya [Upper Angara]; 42 -- Pravomayskaya; 43 -- Churo; 44 -- Nirokonskaya; 45 -- Asindinskaya; 46 -- Yanchuyskaya; 47 -- Kovoktinskaya; 48 -- Verkhnemuyakanskaya; 49 -- Muyakanskaya; 50 -- Verkhnemuyskaya [Upper Muya]; 51 -- Ulanmakitskaya; 52 -- Muyskaya [Muya]; 53 -- Syul'banskaya; 54 -- Baronka; 55 -- Namarakitskaya; 56 -- Taksimskaya; 57 -- Dzhelod; 58 --Kokorevskaya; 59 -- Eymnakhskaya; 60 -- Dovachan;
[continued on p 313]

[Legend and key for Fig 104, p 312 (continued)]:

61 -- Lurbunskaya; 62 -- Ugargasskaya; 63 -- Kuandinskaya; 64 -- Verkhnesyul'banskaya; 65 -- Ingamakitskaya; 66 -- Chineyskaya; 67 -- Verkhnekalarskaya [Upper Kalar]; 68 -- Kemenskaya; 69 -- Charskaya [Chara]; 70 -- Chitkandinskaya; 71 -- Tokkinskaya; 72 -- Khaniyskaya; 73 -- Imangra-Chebarkasskaya; 74 -- Kudulikanskaya; 75 -- Teminkskaya; 76 -- Dzhidinskaya [Dzhida]; 77 -- Gusinoozerskaya; 78 -- Tugnuyskaya; 79 -- Udinskaya; 80 -- Kurbinskaya; 81 -- Zazinskaya; 82 -- Bagdarinskaya; 83 -- Taloyskaya; 84 -- Imamskaya; 85 - Srednekalarskaya [Central Kalar]; 86 -- Kalakanskaya; 87 -- Amalatskaya; 88 -- Krasnoyarovskaya (Vitimskaya); 89 -- Yeravninskaya; 90 -- Khudunskaya; 91 -- Kondinskaya [Konda]; 92 -- Nenyuginskaya; 94 -- Tungirskaya; 95 -- Morikskaya; 96 -- Belo-Uryumskaya; 97 -- Zeleno-Ozerskaya; 98 -- Srednenerchinskaya; 99 -- Usuglinskaya; 100 -- Chitino-Ingodinskaya; 101 -- Beklemishevskaya; 102 -- Khilokskaya; 103 -- Chikoy-Khilokskaya 104 -- Ungo; 105 -- Chikoyskaya; 106 -- Olenguyskaya; 107 -- Olenguysko-Tyrgetuyskaya; 108 -- Altan-Kyrenskaya; 109 -- Ononskaya; 110 -- Kuanginskaya; 111 -- Olovskaya; 112 -- Zyul'zinskaya; 113 -- Shilka-Amurskaya; 114 -- Argunskaya; 115 -- Toreyskaya; 116 -- Urulyunguyskaya; 117 -- Ust'-Karskaya; 118 -- Unda-Dainskaya; 119 -- Sharokuduyskaya; 120 -- Verkhnealdanskaya [Upper Aldan].

Key:

1 -- Tulun; 2 -- Zita; 3 -- Irkutsk; 4 -- Irkut; 5 -- Slyudyanka; 6 -- Dzhida; 7 -- Kyakhta; 8 -- Chikoy; 9 -- Selenga; 10 -- Ulan-Ude; 11 -- Nizhneangarsk; 12 -- Barguzin; 13 -- Upper Angara; 14 -- Lake Bunt; 15 -- Lena; 16 -- Lensk; 17 -- Vitim; 18 -- Romanovka; 19 -- Chita; 20 -- Onon; 21 -- Ingoda; 22 -- Karenga; 23 -- Bukachacha; 24 -- Shilka; 25 -- Nerchinsk; 26 -- Borzya; 27 -- Chara; 28 -- Olekma; 29 -- Ust'-Nyukzha; 30 -- Mogocha; 31 -- Amur.

Ol'khon Island. Along the southeastern slope of the Academic ridge there is a fracture, the signs of which have been established according to the gravimetric data and by sonar (Lut, 1961a; Zorin, 1971).

The maximum flexure of the basement was established in the northern part in the vicinity of the Verkhnyaya [Upper] Angara River delta where the thickness of the Cenozoic sediments reaches 4500 meters. Over the remaining territory of the basin is within the limits of 1 to 3 km, decreasing to the first hundreds of meters in the Malyy Sea (Zorin, 1971). According to the calculations of G. A. Dmitriyev and E. M. Kolokol'tseva (1970), the accumulation rate of the Cenozoic sediments in Northern Baykal over the extent of the entire period of its formation was almost 5 times less than in the southern part of the lake (1.5 and 7 cm per 1000 years respectively). Therefore the time required for the accumulation of the sediment lens in the Northern Baykal basin is determined by these researchers at 40 million years, and in Southern Baykal, at 30 million years. Considering the entire series of versions of

the sediment accumulation for possible elimination of this lack of correspondence, G. A. Dmitriyev and E. M. Kolokol'tseva arrive at the conclusion that the "northern part of Baykal is more ancient than the southern and central parts" (1970, p 73).

However, certain facts have been established in recent times indicating the youngness of the northern basin, the filling of which with water can be classified as the end of the Pleistocene to the beginning of the Holocene.

The loaded (dry valley) basins of the Baykal type include the Tunkinskaya, Ust'-Barguzinskaya, Barguzinskaya, Verkhneangarskaya [Upper Angara], Muyskaya [Muya], Charskaya [Chara], and the Tokkinskaya.

The majority of the enumerated morphostructures, just as the unloaded southern and northern Baykal basins are polystructural grabens. They occurred as a result of the merging of the monostructural basin breaking the longitudinal or transverse mountain commissures separating them.

The Muya basin is a clear example of the still incomplete merging of two subparallel depressions into a united rift structure. We consider it to include the large latitudinal intermontane depression located in the lower courses of the Muya, Konda and Parama Rivers. Its dimensions are 90X45 km. The least absolute elevation of the bottom of the basin is 463 meters, the mean absolute elevation is about 550 meters. On the north and from the south the basin is bordered by the Northern Muya and Southern Muya ridges. On the east it is bounded by the complex block structures of the Muya-Chara interbasin commissure, and on the west by the mountain spurs of the northern and southern Muya ridges. The divide line of the latter is a total of 4 to 5 km from the accumulative boundary of the basin at the same time as this distances increases to 12 to 15 km for the Northern Muya ridge. However, even here many of the peaks with elevations of 1500 and 1900 meters are located 3 to 5 km from the northern boundary of the loose cover of the basin. The average maximum rise of the uplifts surrounding the basis above its accumulative surface is about 1800 meters. The indicated relations characterize the great steepness of the sublatitudinal sides, in cases reaching 35-40°.

The Muya basin is made up of Cenozoic deposits of different composition and genesis. Just as in the other negative structures of the Stanovoy Highland, their section has been studied only in the surface part. The most ancient sediments date from the beginning of the Pleistocene (Zelenskiy, 1971).

The structure of the basin basement according to the geophysical data (Zorin, 1971) is highly complex. As has already been pointed out, the Muya basin is divided by a large longitudinal commissure into two basins -- the Muya-Konda and the Parama. The greatest loading, beginning with the interpretation of the results of the gravimetric observations, was experienced by the southern Muya-Konda depression, the thickness of the loose deposits in which reaches 2100 meters (Zorin, 1971). The region of maximum depths of the crystalline bed is located in the western part of the depression (west of the Vitim River), and it is close to its north

side. In the eastern half, according to the observations of M. V. Ivanov and V. D. Ogorodnikov, the corresponding regions of maximum precipitation accumulation are close to the southern mountain border of the basin. At the same time it is possible to assume a change in nature of the transverse asymmetry of the basement along the longitudinal axis of the depression.

The overall sublatitudinal structure of the Muya-Konda graben is disturbed by a comparatively small inlet-type depression of higher order (the satellite basin) going deeply into the southern mountainous border. It is located on the southwest point of the depression and is elongated in the north-northeast to the direction along the Mudirikan, Anevrikan, and Ana Rivers. The transverse profile of the depression is sharply asymmetric: the south-eastern steep side of it is cut by a powerful fault, the apparent amplitude of the displacement along which is no less than 700 meters. The opposite side is gently sloping; it is formed by the slopes of the submeridional mountain spur of the Southern Muya ridge smoothly plunging to the east, which simultaneously from the west bounds the Muya-Konda basin. In its eastern part the analogous satellite basin extends to the northeast along the Syul'ban River, entering into the boundaries of the Muya-Chara inter-basin commissure.

The northern, Parama depression has a significantly simpler structure. The thickness of the Cenozoic sediments here does not exceed 600 meters, and the maximum plunging of the basement is along the foot of the northern mountain border (Zorin, 1971). The south limb of the basin rises gently to the intrabasin commissure. From the west and north it is separated from the Northern Muya uplift by zones of faults of submeridional and sublatitudinal strike active in the Cenozoic. The amplitude of the vertical displacement along them is from 500 to 2000 meters.

The intrabasin commissure separating the two depressions is a low-mountain ridge rising 200 to 400 meters above the accumulative surface of the basin. It is basically made up of Archean rock and extends in a narrow (4-8 km) strip in the sublatitudinal direction along the left bank of the Muya River. East of the Vitim River the commissure continues through the outcrop of the basement at the village of Pargolino on the right bank of the Konda River. The north slope of the ridge, judging by the sinuous contact line of the loose deposits in the crystalline basement and also by the geophysical data, smoothly plunges in the direction of the Parama depression. The south slope is expressed by a sharp rectilinear scarp steeply falling toward the Muya-Konda depression. Already 2 to 3 km south of the scarp the basement of the depression is at a depth on the order of 1000 to 1500 meters. In addition, the fault nature of the southern slope of the commissure is indicated by the seismogeological observations and thermal springs located in the mouth part of the Muya River. The fault along the left bank of the Muya east of Vitima obviously changes in echelon fashion with another tectonic disturbane of sublatitudinal strike hidden under the loose deposits and completing the structural formation of the Muya-Konda depression on the north.

Thus, the Muya depression has entirely symmetric structure and is a polystructural graben. The negative structures of higher order within its limits have both "Baykal" asymmetry and asymmetry opposite to it. In addition to the above-noted sublatitudinal tectonic disturbances, the faults of submeridional (20-30°) and northeasterly (60-70°) direction participate in the formation of the modern structural tectonic appearance of the basin and the block differentiation of its basement. The first of them is exhibited predominantly in the western half of the basin, outlining its distal boundaries here, and the second, on approaching the Muya-Chara interbasin commissure. In addition, in the crystalline basement of the basin, the system of disturbances of the northwesterly strike has been established coinciding with the orientation of the pre-Cenozoic (primarily Proterozoic to Lower Paleozoic) folded and ruptured structures. These disturbances are obviously passively rejuvenated during the formation of the rift.

The most common feature of the mature basins of the Baykal type having significance for estimating their seismotectonic potential is the mosaic-block, sometimes extremely complex structure of the crystalline bed. This is demonstrated, in particular, by the presented examples of the Southern Baykal and Muya basins. In the last case the longitudinal mountainous commissures separating the morphostructure into two depressions can become a region of occurrence of centers of strong earthquakes which will only be a reflection of the noted trend toward merging of the Muya-Konda and Parama basins. The analogous picture is observed on the southwest flank of the Baykal rift zone in the Tunka system of basins where the Nilovskaya and Yelovskaya crystalline commissures are gradually encompassed by riftogenic faults, they are fractured and separated from the mountain border in the direction of the basins -- a situation almost repeating the "absorption" of the mountain block of the Southern Muya ridge by the southern part of the Muya-Konda basin in detail (see Figures 102, 103).

A characteristic feature of the mature basins and the proof of their growth as a result of mountain uplifts is the presence in the side parts of the depressions of parallel fault zones predominantly at a distance of 2 to 5 km, between which the oblique foothills plains or sections of the slopes are included. For example, on the western shore of Baykal between the shore and highland faults there are great seismic structures of Rita, Shartlay, Kedrovaya and so on created by force 12 earthquakes. North of them the system of paleoseismodislocations traced with discontinuities at a distance of about 140 km (the seismostructures of Kedrovaya, Solontsovaya, Khibelenskaya) occurring during the force 10 earthquakes are associated with analogous morphostructural elements.

On the east coast of Baykal between the lake and shore fault during the Tsaganskiy force 10 earthquake of 1862 the tectonic block about 260 km^2 in area drops 7 to 8 meters. The subsidence by 10 to 15 meters of a section of the bottom of the lake was observed here also during the Central Baykal force 10 (M=6-3/4) earthquake of 29 August 1959 (Solonenko, V., Treskov, 1960). The block between the faults experienced a strike-

slip displacement at this time. The examples of the analogous seismotectonic buildup of the Baykal basin at the expense of its peripheral parts are provided by the Istokskiy and Posol'skiy Sors, the subsided blocks of the Listvenichnyy Bay and the Tyya River delta, the cutoff rocky capes protruding into Baykal which we discussed earlier.

In recent years in the vicinity of the Baykal basin deep seismic sounding has been carried out (Puzyrev, et al., 1973, 1974). Here it was discovered (Fig 105) that the seismically active rift morphostructures falling into the observation field (Southern Baykal, part of the Barguzin basin) clearly extend toward the sections with thinned earth's crust, just as the majority of such morphostructures in the Baykalo-Stanovoy zone (Zorin, 1971). Thus, the thickness of the earth's crus in the Southern Baykal basin is 34-36 km, and in the less seismically active Northern Baykal basin,[1] 39.5 to 44 km.

However, this rule obviously is valid only for the Baykal rift, for under the Barguzin depression the thickness of the curst is 40.5 to 43 km, and it is nevertheless highly seismic. The thickness of the crust under the like ridge here is 41-46 km.

A scarp up to 3-6 km high in the mantle expressed by uplift of the Moho boundary is placed in practice along the entire west outline of the Baykal rift, coinciding in plan with the zone of the Obruchev fault. The Baykal rift turns out to be located above the northwestern edge of the broad (to 200 to 400 km across) region with velocity of the elastic waves in the tops of the mantle reduced to 7.7-7.8 km/sec (Puzyrev, et al., 1973). The southeast boundary of this anomalous mantle zone is 200-300 km from Baykal. It cuts the large geological structures of ancient age and only in places is controlled by the deep faults. The vertical thickness of this deconsolidated zone in the mantle exceeds 10 to 12 km and possibly reaches 20 km (Puzyrev, et al., 1973).

A sharp contradiction between the deep seismic sounding data and the seismologic determination of the thickness of the earth's crust by the reflected waves of the earthquakes interpreted by S. I. Golenetskiy arises only for the vicinity of the Ust'-Barguzin basin (44-48 and 36-38 km respectively). For part of the Siberian platform adjacent to the vicinity of the Baykal rift, the thickness of the crust according to the data of these two methods is close to 39 km.

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[1]According to the data on the reflected waves of the earthquakes in the interpretation by S. I, Golenetskiy, the thickness of the earth's crust under these depressions is 32-36 and 40-45 km, respectively.

Figure 105. Depths with respect to the mantle surface in the Baykal region and Transbaykal according to the deep seismic sounding data and observations of earthquakes.

1-4 -- Depths to the mantle surface (deep seismic sounding), 1 -- according to the reflected wave data, 2 -- according to the refracted wave data, 3 -- depths at the point of exit (entrance) of the refracted waves, 4 -- sharp scarps in the mantle surface; 5 -- isohypses of the basement surface of the Barguzin basin (according to Yu. A. Zorin); 6-7 -- depths to the mantle surface according to the observations of earthquakes interpreted by S. I. Golenetskiy; 6 -- depths according to the reflected wave data (in the numerator, according to the transverse waves, and in the denominator, longitudinal waves), 7 -- depths according to the data of the reflected exchange waves.

The most important consequence for seismotectonics from the deep seismic sounding data is proof of the especially complex deep structure of the earth's crust in the commissure section between the Southern Baykal and Northern Baykal basins. The analysis of the depth map for the mantle surface in this section indicates the following.

The zone with anomalously shallow depths to the mantle surface characteristic of the Southern Baykal basin (34-36 km) follows in a wide band from the vicinity of the mouth of the Bugul'deyk River along the southeastern boundary of Ol'khon Island and reaches the Barguzin Bay where the thickness of the crust is 35 km. At one of the points of this strip (in the center of the southeastern shore line of Ol'khon Island) the crust thickness is 40 to 41 km according to the reflected earthquake waves. However, the accuracy of the determination does not exclude displacement of this point to the north, to the vicinity of Ol'khon Island.

The zone with anomalously deep depths (40.5-42.5 km) with respect to the mantle surfaces encompasses all of the Maloye Sea, Ol'khon Island, and, extending to the northeast, protrudes into the northern Baykal basin. The thickness of the earth's crust somewhat north of Khoboy Cape is 42-43 km. The sharp scarp in the relief of the mantle surface (Duzyrev, et al, 1973) separating the two noted zones with different crust thickness follows from the northeast extremity of the Ol'khon Island (the vicinity of Izhimey Cape) precisely to Nizhniy Izgolov'ye of Svyatoy Nos Peninsula. Here, in the vicinity of the interbasin commissure, a deep trough is noted in the mantle surface, "complicated in its central part by a sharp uplift, that is, there is a type of combination of two polarly opposite forms -- "root" and "antiroot" with contrast variation of the depths to the M boundary in the range of 35-44 km. In the other profiles, this combination is not discovered (Puzyrev, et al., 1973).

It was noted above that the thinning of the crust under the basins can be one of the signs of increased seismicity of them. The fact that the most clearly expressed "antiroot" was detected by deep seismic sounding in the vicinity of the interbasin commissure is one proof of the correctness of the previously drawn seismotectonic conclusion regarding the increased seismic potential of the interbasin commissures which during the course of their seismogenic decay are converted to the bottom of the negative morphostructures. The signs of seismic destruction of the southeastern part of the island of Ol'khon are present: according to our observations, in the vicinity of Izhimey Cape in the coastal denudations excellently expressed slip surfaces were retained hundreds of square meters in area. They fix the chopped shore capes and are none other than the remains of the displacers on relatively uplifted walls of the faults, the opposite limbs of which are dropped to the depths of Baykal. The seismogenic destruction of Svyatoy Nos Peninsula both by the highland and coastal paleoseismodislocations was established by A. D. Abalakov (1973).

Accordingly, it is impossible to consider the explicitly recent submersion under the level of Baykal of the now underwater Academic ridge, the sediment accumulation on the top of which is in the initial stage (Lut, 1964) accidental.

Thus, the seismotectonic absorption by the rift basins of the mountain commissures separating them obviously has a deep cause -- growth (or formation) of the "antiroot." The interrelation of these phenomena leading, in the final analysis, to the creation of mature polystructural grabens with thinned crust does not, in the opinion of Yu. A. Zorin (1971), contradict the physical essence of the riftogenesis process.

The scale and the contrast of the neotectonic movements in the majority of the mature negative morphostructures is only somewhat less than those noted for the Southern Baykal basin. Thus, for example, in the border of the Tunkinskaya depression the height of the Tunkinskiye peaks (maximum absolute elevation 3000 meters) above the bottom of the basin (maximum absolute elevation 550 meters) is about 2500 meters. The crystal bed of the basin according to the geophysical data is at a depth to 3000 meters (Florensov, 1960a, Zorin, 1971). Consequently, the amplitude of the vertical displacements of the blocks of the earth's crust in the Neogene to Quaternary time is about 5500 meters. This figure indicates primarily the rate of the differential vertical movements along the Tunkinskiy fault. It is unquestioned that the indicated magnitude of the vertical displacements also contains the "plastic" component,for it includes the amplitude of the neotectonic distortion of the basement, but it is impossible still to consider it in the given case.

For the approximate calculation of the speed of the differentiated vertical movements, we provisionally consider all of the coal-bearing sediments and the sediments above the coal-bearing ones in the Tunkinskaya basin to belong to the Tertiary period, including only the Pleistocene deposits in the Anthropogene. The maximum thickness of the latter is about 500 meters (Logachev, 1958; Florensov, 1960a). The thickness of the Tertiary formations reaches 2400 meters. Considering the sediment accumulation time (the Neogene is 25 million to 30 million years, the Anthropogene, about 1 million years), we must state that the sedimentation rate and, consequently, the sagging rate of the bottom of the depression increased in the Quaternary period by no less than six times. According to the calculations of V. V. Ruzhich (1972), at the end of the Pliocene and in the Quaternary period, the rates of sagging of the bottom of the Tunkinskaya basin increased by comparison with the Neogene by one order and amounted to 1-2 mm/year. It is natural that this led to an increase in the seismotectonic activity of the Tunkinskaya basin which is indicated, in particular, by the series of strong (to force 9) earthquakes of the 19th to 20th centuries.

The overall scale of differentiated vertical movements considering the absolute altitude of the mountain border of the Ust'-Selenga depression (1200-1450 meters) reaches 8000 to 8500 meters here. The thickness of the molasse deposits of the Eopleistocene-Holocene for the basins of the Baykal system is estimated at 500 to 1200 meters (Logachev, 1968). In the Proval Bay, the drilling stopped in the Quaternary sands at a depth of 334 meters (Zamarayev, Samsonov, 1959). According to the date of N. A. Logachev (1968), the Quaternary sands up to 300-400 meters thick make

up almost half of the area of the majority of dry valley basins of the Baykal system. Therefore it appears basic to consider the minimum thickness of the Quaternary deposits in the Ust'-Selenga depression equal to 500 m (Zamarayev, Samsonov, 1959). A comparison of the thicknesses of the Upper Paleogene-Neogene[1] (to 8000 meters) and the Quaternary formations with a duration of the sediment accumulation (40 million and 1 million years) indicates that the sediment accumulation rate and, consequently, the submersion of the crystal basement in the Quaternary period increased by 2.5 times. This indicates an increase in the rate of the neotectonic process, as a result of which the seismic activity of the Ust'-Selenga depression increases. Let us note that just as in the case of the Southern Baykal basin, the intensity of these phenomena is caused primarily by the descending and not the ascending shifts of the different sections during the course of the bending of the crystal substrate. This is clearly confirmed by the incompatibility of the amplitudes of the downwarping of the basement of the depression and the heaving of the arched ridges bordering it (about 8000 and 1200 meters respectively). The downwarping rate of the basement exceeds by almost six times the rate of uplift of the ridges. During the historical time, movements of a negative sign also predominated. These include the formation of the Proval Bay and probably, previously, the Posol'skiy and Istokskiy Sors, the deformation of the Selenga River terraces, the submersion of the peat beds under the waters of Baykal and also the subsidence of the bottom of the lake by 10 to 15 meters during the earthquake of 29 August 1959 (Solonenko, V., Treskov, 1960).

Thus, the subsidence rate of the basement of the basin on the southwest flank of the Baykal rift zone increased in the Anthropogene by 2.5-6 times by comparison with that in the Neogene. Similar relations are characteristic also for other mature basins. This caused high modern seismic activity which is confirmed by the association of a large number of earthquake epicenters with the mature basins.

The zones of the activated faults bounding the basin, somehow "thread" on themselves the plaeoseismogenic structures -- epicentral regions of large seismic disasters of the recent past. The seismic potential of the activated faults and the interbasin commissures has been investigated separately. The remaining elements of the mature negative morphostructures represented predominantly by the central parts of the troughs with thick beds of Cenozoic sediments have different potential seismicity:

1. M=4-3/4 to 5-1/2 (force 7-8). The Ust'-Barguzin depression in the central parts of the mature basins -- Northern Baykal, Upper Angara, Barguzin, Muya-Konda, Parama and Chara. Active faults have not been established in the basements of these basins.

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[1] If we begin with the recognition of the Paleocene-Eocene weathering crust in the Baykal region (Logachev, 1968), then provisionally the Upper Paleogene deposits isolated in the Ust'-Selenga depression by V. V. Samsonov and G. P. Ponomareva (1970) can be considered Oligocene.

2. M=5-1/2-6-1/2 (force 8-9). The Tunkinskaya system of basins, with the exception of the vicinity of the fault with the same name; central part of the Southern Baykal basin, with the exception of the region with maximum expressed differentiation of the basement; the northeastern part of the Upper Angara basin and the eastern part of the Muya-Konda depression with the proposed active faults in the basement.

3. M=6-1/2-7 (force 9). The southeastern part of the Ust'-Selenga depression with actively growing Tvorogovo-Istokskiy uplift.

4. M>7 (force 10 or more). Part of the southern Baykal basin with sharply expressed differentiation of the basement; the delta trough of the Ust'-Selenga depression with a plunge amplitude of the basement to 6000-8000 m bounded on the northeast by "active" faults. The high seismic potential here is confirmed also by the calculations of the long-term seismic activity by the geophysical data (see Figures 98 and 99).

The fading or infantile basins are only morphologically similar to embryonic ones. On the shore of Baykal they are oriented parallel to the shorelines of the lake and they are separated from it by low coastal mountain ridges (Kotokel'skaya, et al., on the east shore, Kocherikovskaya, et al., on the west coast). These shallow troughs began to be formed obviously simultaneously with the other large Baykal basins, but the process of their development, for still unknown reasons, occurred extremely sluggishly. Probably, the inclined planes of the vicinity of the Pokoyniki-Solontsovyy Capes are marginal members of such "infantile" basins. However, they cannot be considered entirely stable. This is indicated by the seismic activity of the Kotokel'skaya basin with which the epicenters of the earthquakes up to force 7 are coordinated (for example, 7 October 1960, M=5-1/2).

The fault basins are the unclear type (Oka in Eastern Sayan, Kolokskaya and Yambuyskaya on the Primorskiy and the Ikadskiy ridges respectively). On the other hand, the clear morphological expression, asymmetry, presence of Cenozoic loose deposits and even basalt flows, which is characteristic of the basins of the Baykal type are characteristic of them, and on the other hand, their modern development does not correspond to the requirements of the purely riftogenic process. At the present, they are either involved in the uplift and are developing under the conditions of predominant compression (the Oka basin) or they are passive structural elements (Yambuyskaya and Kolokskaya) of the rift zone. With respect to their dimensions they correspond to the embryonic values, for which high mobility and seismotectonic activity are characteristic. For the final solution to the problem of the genesis of these negative structures and their seismic potential, special detailed geological-geophysical studies are required.

Activated Faults and Main Seismically Active Zones

In the generalized papers on the latest tectonics and seismotectonics of the mountain belt of Eastern Siberia (Florensov, 1960; ACTIVE TECTONICS..., 1966; SEISMOTECTONICS..., 1968, 1975a, b) it is recognized that in the

formation of its modern the primary role goes to the vertical tectonic movements of the earth's crust which were accompanied both by plastic (bending) and discontinuous deformations. Here the general dynamic (and seismotectonic) situation of the Neogene-Quaternary stage of development of this territory was regulated by the formation of the main morphostructural elements -- the arch-block uplifts and systems of Baykal rift and subrift basins.

Recognizing the important role of the bending deformations, it is necessary to note that the neotectonics of the mountain belt of Eastern Siberia, especially the "active (Holocene) tectonics," is determined primarily by the development of the large systems of activated faults (see Fig 106) such as, for example, the Main Sayan fault, Obruchev, Stanovoy, and so on. The large faults entering into these systems, as a rule, deep, long-lived, control the development of the principal morphostructures. The existing concept of the development time for such faults, the multiple rejuvenation of the displacements along them during various geological periods has been proved by numerous observations. As for the rate and the regimen (the type and direction) of the shifts along the fault, the seismogeological practice has demonstrated that they can be both prolonged, slow, "creeping" (tectonic creep), and sharply, discontinuous (characteristically seismic). This situation now definitely follows from a great deal of the factual material on the Mongolo-Baykal seismic belt and is proved by direct observations of the San Andreas fault regimen (Allen, et al., 1965; Anderson, Donell, 1971; Wellman, 1972). Moreover, the seismogeological studies of the faults prove the presence in them of inversion zones of the tectonic movements -- changing of the direction of the displacement to the opposite sign. Here the inversion nature of the movements is noted both along the normal faults and the upthrow faults and with respect to shifts.

The activated faults have an important role in estimating the level of potential seismicity of the various structural elements of the earth's crust. These suture zones which delimit the morphostructures which are different with respect to type, rate and direction of the neotectonic movement are the main seismically active lines with which the overwhelming majority of apicenters of the strong earthquakes and paleoseismogenic structures are closely connected both spatially and genetically. Thus, for seismotectonics, the activated faults expressed in the relief and realizing the morphostructural control and their spatial connection with the epicentral fields are of special interest for seismotectonics. Numerous seismogeological data on the territory of Eastern Siberia indicate that the epicenters of the earthquakes and the epicenters of the earthquake swarms extend to the lineaments. It is true that a comparison of the epicentral fields with the plan configuration of the discontinuous structures reveals high correlation usually on the maps of survey scales. On the whole, the small possibility of tying the epicenters of the moderate and weak earthquakes to the specific faults increases significantly in the case where they are actively expressed in the relief and have clear morphological signs of seismogenic rejuvenation.

Therefore, although when analyzing the relation of the earthquake epicenters and the epicenters of the activated faults it is still more correct to talk about their overall area relationship and not the unique tying to a specific fault, it is in such seismogeological relations that the paths of quantitative analysis of defined morphostructural elements are noted from the point of view of the potential seismicity.

Morphologically, the zones of activated faults are extended (by hundreds of kilometers) lineaments, as a rule, made up of individual echelons, each of which is clearly expressed in the relief. The problem of the degree and nature of expression of the faults in the relief has independent overall morphological significant. In addition, by the nature of this expression the geomorphological (surface) phenomena become the criterion for the seismotectonic (deep) role of the faults. The usual morphological signs of the "seismogenerating" (activated) faults are extended and rectilinear, often echelon steep scarps in the foothills relief. Frequently, they are accompanied by triangular facets -- flat steep cuts of the mountain spurs on the sides of the negative morphostructures. Usually these forms make up a sort of "plane front" at the transition of the mountain slopes at the bottom of the depressions (for example Tunkinskiy, Barguzin, Kodar, and other faults). Often in the zones of such faults chains of linearly extended saddles are formed in the mountain spurs and divides or systems of tectonic asymmetric semi-extended trenches in which absorption of coarse lump talus-proluvial material takes place. In addition to the clear geomorphological expression, such zones usually are emphasized by crushing, intensive jointing of the rock and their dynamometamorphic alteration (mylonites, cataclasites, tectonic breccia, slip plains, and so on). An entire series of other attributes of activated faults -- hydrogeological, hydrographic, geophysical, stratigraphic, and son on -- have been isolated.

Genetically, the majority of the activated faults are normal faults and upthrow faults, frequently with a small shift component. In many cases geomorphologically and also by structural analysis of the slip plains in the zones of such faults traces of successively occurring left and right horizontal shifts are discovered. This is why we see the shifts in the seismogenic ruptures connected with the given earthquake and we do not find convincing proof of significant horizontal shifts with respect to the long-lived faults. Independently of the shift amplitudes, as a rule, very small ones (first meters), this phenomenon indicates the secondary role of the shift component in the tectonic movements along the young rift-forming faults. Examples of modern seismodislocations (in particular, with respect to the Muya earthquake of 1957) indicate that the horizontal (shift) displacements are 3 to 4 times less than the amplitude of the vertical displacements ACTIVE TECTONICS..., 1966). On the whole, for the zones of activated faults of the Baykalo-Stanovoy zone the shift component is felt little, which is also confirmed by the special study of the mechanism of earthquake centers (see Chapter V).

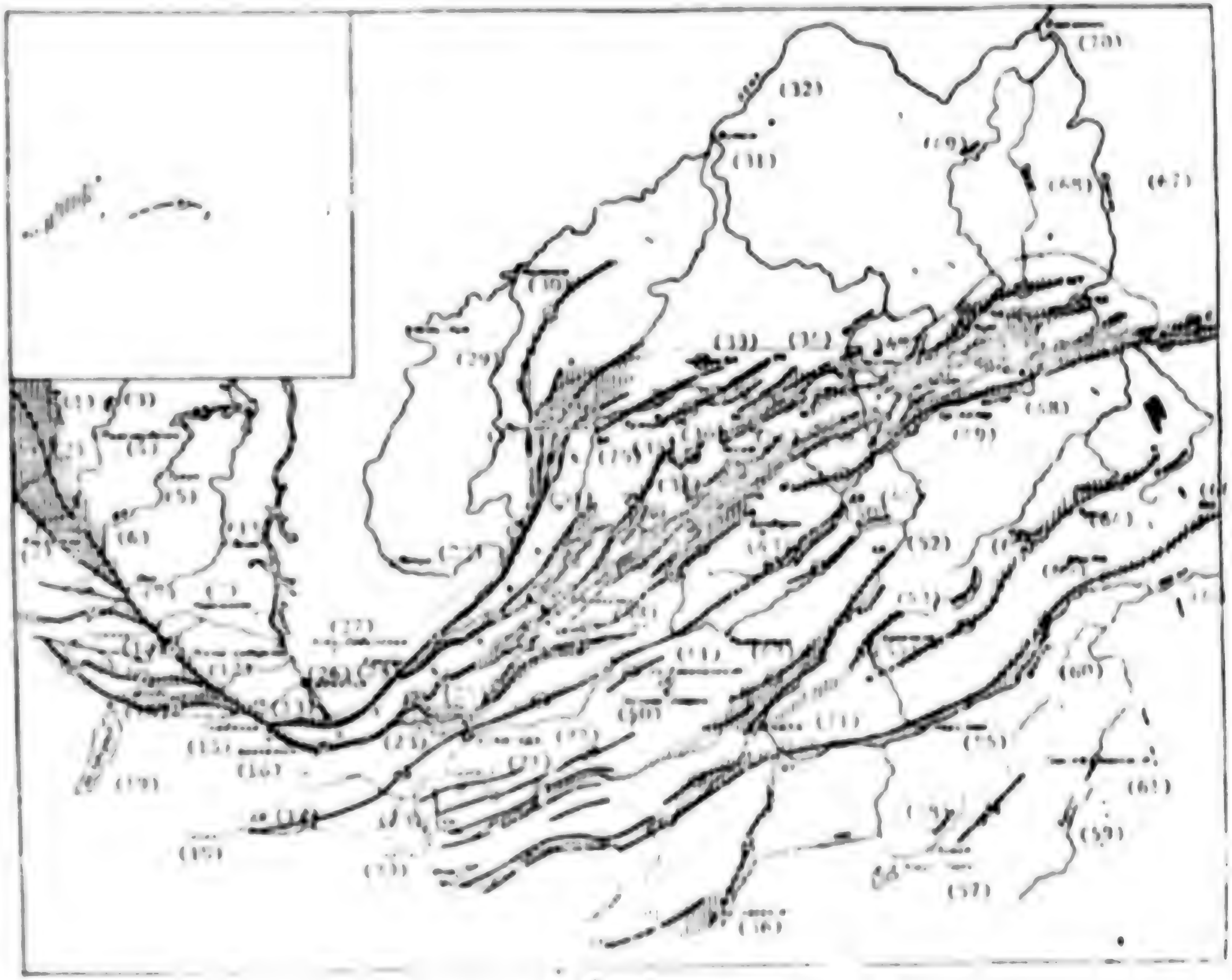

Figure 106. Schematic of the most important faults of epiplatform orogenic belt of Eastern Siberia active in the Cenozoic. Compiled by M. G. Dem'yanovich.
[Legend and key, p 325]

[Legend and key for Fig 106, p 324]:

1 -- Systems of faults and their abbreviated names; 2 -- faults and their numbers on the list; 3 -- boundary of the Baykal rift zone; name of the system of faults and the components of their individual dislocations with breaks in continuity: GS -- Main Sayan deep fault: 1 -- Main Sayan, 2 -- Biryusinskiy [Biryunsa], 3 -- Okinskaya [Oka], 4 -- Kitoyskiy, 99 -- Dototskiy, O -- Obruchev: 5 -- Tunkinskiy- 6 -- Primorskiy, 7 -- Northern Baykal, 8 -- K(?)icherskiy, 9 -- Tyya-Abchadskiy, 10 -- Gramninskiy, 11 -- Pogranichnyy, 12 -- Akitkanskiy, OV -- Ol'khonskaya [Ol'khon] branch of the Obruchev system, 13 -- Ol'khon, 14 -- Svyatonosskiy [Svyatoy Nos], 15 -- Chivyrkuyskiy, 16 -- Kabaniy, 17 -- Bol'sherechen(?)skiy. Ch --Cherskiy: 18 -- Cherskiy, 19 -- Del'tovyy, 20 -- Bezymyannyy [unnamed], 21 -- Katkovskiy, 22 -- Nalimovskiy, ST -- Selenga-Turkinskaya branch of the Cherskiy system: 23 -- Selenga, 24 -- Khamarskiy, 25 -- Turkinskiy, B -- Barguzin: 26 -- Ulyuchikanskiy, 27 -- Shamanskiy, 28 -- Turaki, VA -- Verkhneangarskaya [Upper Angara]; 29 -- Verkhneangarskiy [Upper Angara], 30 -- Pravomanskiy [Right Mama], UK -- Ukolkitskaya; 31 -- Ukolkitskiy, 32 -- Kovoltinskaya, ITs -- Ikat-Tsipikanskaya; 33 -- Maraktakanskiy, 34 -- Garginskiy, 35 -- Ulan-Burginskiy, 36 -- Dzhargolanta Nerungdinskiy, 37 -- Tsipikanskiy, 38 -- Gorbylokskiy, 97 -- Ikatskiy, BV -- Barguzino-Vitim; 39 -- Yambuyskiy, 40 -- Marekta-Mukdekenskiy, 41 -- Vitimkanskiy, DV -- Dzhida-Vitim; 42 -- Dzhida, 43 -- Khambinskiy, 44 -- Uda, 45 -- Amalatskiy, 46 -- Zazinskiy, 47 -- Verkhnevitimskiy [Upper Vitim], TT -- Tugnuyskaya: 48 -- Tugnuyskiy, 49 -- Zaganskiy, 50 -- Kichingskiy, KhK -- Khilok-Karengskaya; 51 -- Khilokskiy; 52 -- Yuzhnokhilokskiy [Southern Khilokskiy], 53 -- Beklemeshevskiy, 54 -- Karengskiy, MO -- Mongolo-Okhotsk deep fault: 55 -- Kudarinskiy, 56 -- Chikoyskiy, 57 -- Zachikoyskiy; 58 -- Pravo-Ingodinskiy [Right Ingoda], 59 -- Levo-Ingodinskiy [Left Ingoda], 60 -- Shilkinskiy [Shilka], Nizhnenerzhuganskaya branch of the Mongolo-Okhotsk system: 61 -- Nerchuganskiy, 62 -- Verkhnetungirskiy, OT -- Onon-Turinskaya: 63 -- Ononskiy, M -- Muyskaya [Muya]; 64 -- Muyakanskiy; 65 -- Verkhnemuyskiy [Upper Muya], 66 -- Ulan-Makitskiy, 67 -- Nizhnemuyskiy [Lower Muya], 68 -- Paramskiy [Parama], MT -- Muya-Tokko: 69 -- Mudirikanskiy, 70 -- Yuzhno-Muyskiy [Southern Muya], 71 -- Syul'banskiy, 72 -- Kodarskiy [Kodar], 73 -- Tokkinskiy [Tokko], ChKh- Chitkanda-Khaniyskaya branch of the Muya-Tokko system: 74 -- Chitkandinskiy, 75 -- Khaniyskiy. TsB -- Tsipa-Bauntovskaya: 76 -- Tsipinskiy [Tsipa], 77 -- Bauntovskiy; 78 -- Kudurskiy, 79 -- Tilishminskiy, 80 -- Bambuyskiy, 81 -- Taksima-Dzhilindinskiy, U -- Udokanskaya [Udokan]: 82 -- Namarakitskaya, 83 -- Konda-Eymnakhskiy, 84 -- Dovochanskiy, 85 -- Lurvinskiy, 86 -- Emetachi-Kemenskiy, 87 -- China-Vakatskiy, 88 -- Katuginskiy, 89 -- Chepinskiy, K -- Kalarskaya [Kalar]: 90 -- Ust'-Tsipa, 91 -- Nizhnekalarskiy [Lower Kalar], 92 -- Dzhelo, S -- Stanovoy deep fault: 93 -- Tas-Yuryakhskiy, 94 -- Imangrskiy, 95 -- Stanovoy, 96 -- Yuzhno-Stanovoy [Southern Stanovoy]. Individaul faults, 98 -- Gazimurskiy, 100 -- Tissinskiy [Tissa], 101 -- Fofanovskiy.

[Key to Fig 106, p 326]

[Key to Fig 106, p 324]:

1 -- Biryusa; 2 -- GS; 3 -- Uda; 4 -- Nizhneudinsk; 5 -- Tulun; 6 -- Iya; 7 -- Alygdzher; 8 -- Oka; 9 -- Cheremkhovo; 10 -- Orlik; 11 -- Zita; 12 -- Usol'ye-Sibirskoye; 13 -- GS; 14 -- Mondy; 15 -- Slyudyanka; 16 -- Baykal'sk; 17 -- DV; 18 -- Zakamensk; 19 -- Lake Khubsugul; 20 -- Kyakhta; 21 -- Gusinoozersk; 22 -- Ulan-Ude; 23 -- ST; 24 -- Selenga; 25 -- Yelantsy; 26 -- Irkutsk; 27 -- Ust'-Ordynskiy; 28 -- Kachug; 29 -- Ust'-Kut; 30 -- Kirensk; 31 -- Vitim; 32 -- Lena; 33 -- VA; 34 -- UK; 35 -- Kumora; 36 -- UK; 37 -- Barguzin; 38 -- Barguzin; 39 -- BV; 40 -- Sosnovo-Ozersk; 41 -- Yeravninskiy Lake; 42 -- Romanovka; 43 -- Bagdarin; 44 -- Uakit; 45 -- MT; 46 -- Vitim; 47 -- Nelyaty; 48 -- Kalar; 49 -- Central Kalar; 50 -- DV; 51 -- Lake Baykal; 52 -- KhK; 53 -- Karenga; 54 -- Bukachacha; 55 -- Nerchinsk; 56 -- Khapcheranga; 57 -- Borun-Torey Lake; 58 -- Borzya; 59 -- Argun'; 60 -- Shilka; 61 -- Gornyy Zerentuy; 62 -- Amur; 63 -- Tungir; 64 -- Tupik; 65 -- Mogocha; 66 -- MO; 67 -- Olekma; 68 -- Tokko; 69 -- Chara; 70 -- Olekminsk;; 71 -- Chita; 72 -- Nyukzha; 73 -- Chikoy; 74 -- Nizhneangarsk; 75 -- VA

The main (trunk) activated faults are often accompanied by short (to the first tens of kilometers) feathering and accompanying fractures playing an important role in the development of the fine block structures in the sections near the faults. The amplitudes of the vertical displacements along certain faults are different, and they depend both on the age and the morphogenetic type of the structures than on the speed and direction of the latest tectonic movements. Here the greatest amplitudes of the vertical displacement (to 3000 to 7000 meters) are noted by the activated faults bounding the mature morphostructures of the Bayk l basins maintaining a stable trend toward subsidence during the entire period of rift formation. The least displacement amplitudes tens to a few hundreds of meters) are noted with respect to the activated faults of the youngest basins of the evolutionary series and also in the sections of inverted infantile rift and subrift basins.

With respect to degree of inheritance of the pre-Cenozoic structural plan and alteration of it by the latest tectonic movements the mountain belt of Eastern Siberia is extremely nonuniform: along with the areas of prolonged inherited development here, the zones of sharp and single structural rearrangement are widespread. Analyzing the strict spatial localization of the basins of the Baykal site, the systems of activated faults controlling these axial structures and the ratio of the Cenozoic and ancient structural plans, N. A. Florensov (1960a,1964, 1968) showed that the rift zone extending spatially to the ancient marginal suture of the Siberian platform is distinguished by sharp superposition of the substrate structures, to Tertiary.

The opinion of V. P. Solonenko regarding the genetically independent development of the Baykal rift system with respect to the ancient structures is still more definite. "The Baykal rift zone is adjacent to the marginal

southern projection of the Siberian platform only over a short segment, and then it deflects sharply away from it, in spite of the presence at the platform boundary of powerful marginal tectonic sutures -- the Sayan fault zone. The secondary role of the Siberian platform and the pre-Baykal deep fractures is traced quite clearly here... The basins, Kosogol'skaya and Barkhatskaya, in general go from the field of Baykal folding to the Caledonian... The Barguzino-Bauntovskaya and Upper Angara branches of the basins are still more removed from the Siberian platform. In the Stanovoy sector the rift zone intersects the system of Baykal folding, the Muya central massif, the Chara block, and it cuts by one branch into the Aldan shield and by the other, into the region of Proterozoic folding of Stanovik...

The deep and large regional faults of the pre-Baykal occurrence form a dense network in the region of Cenozoic orogenesis. It is entirely natural that some of them, just as the weakened zones of the earth's crust, are encompassed by rift formation, but they have only promoted and have not predetermined the place of occurrence of the rifts... Therefore in the seismogeological estimate of the fault zone it is necessary to discover in detail the degree of their participation in the rift formation and "active" tectonics. The powerful fault zone is well expressed geologically and even geomorphologically, can turn out to be seismically passive, and the unexpressed young or pre-Baykal faults, recently involved in rejuvenation (for example, in the embryonic basin zones), highly "active" (Solonenko, V., 1968a, pp 69-70).

The morphostructures located outside the rift zone have inherited to a significant degree the structural-tectonic plan of the preceding stages of development, and the principle of inheritance on the whole is maintained both with respect to the ancient and young faults and with respect to the folded complexes. All of this is felt to one degree or another in the variety of structural forms which are the result of the prolonged history of geological development of the mountain belt of Eastern Siberia, and in the final analysis it finds its expression in the peculiarities of the manifestation of seismicity. The most highly seismic regions are isolated in the axial part of the Baykalo-Stanovoy zone where as a result of predominant extension, there is complex block differentiation of the earth's crust with the formation of an extended system of rift basins and the block and arch-block uplifts bordering them. The intensive seismotectonic development of this zone in which the primary role is played by the systems of activated faults influences the bordering territories and causes increased seismic potential of the adjacent zones of activation of the southern part of the Siberian platform and the Mongolian-Okhotsk folded belt.

The seismogeological relations are varied. As the basic relations it is possible to indicate the relation of the earthquakes to the zones of activated faults, the blocks of sharply differentiated tectonic movements, the sections of local rearrangement of the Cenozoic and more ancient structures of the plans by the riftogenic processes, the marginal parts of the regions of stable subsidence or uplift, the interbasin and intrabasin

mountain commissures, the areas of the intersection and echelon type articulation of the latest morphostructures, especially the large fracture zones to the embryonic basins, the sections of manifestation of the latest volcanism, and so on.

In many papers on the various seismically active regions when discovering the laws of the relation of earthquakes and the geological structure, not only the seismological but also the geological-tectonic criteria of the occurrence of earthquakes are given. In recent times studies have been made from these complex seismotectonic points of view of the seismically active regions of Mongolia and Pribaykal'ye, Central Asia and the Caucasus, and abroad -- Southern California, Alaska, Japan, New Zealand and so on (Gubin, 1960; Solonenko, V., et al., 1960b; Petrushevskiy, 1960, 1964; Gobi-Altay..., 1963; ACTIVE TECTONICS..., 1966; SEISMOTECTONICS..., 1968, 1975a, b; Kuchay, 1969; Medvedev, et al., 1971; Allen, et al., 1965; and so on). Here the main role was given to the deep and crystal activated faults having important significance in the seismotectonic development of the morphostructural elements and in estimating the level of their potential seismicity.

In the different stages of their development and depending on the morphogenetic type of bounded structures, the seismotectonic role of the activated faults can be different. For example, they can be zones of release of the most powerful seismic stresses, but in the case of "transitional" tremors usually part of the energy of the seismic waves is absorbed, causing an irregular decrease in strength of the earthquake. In one way or another the zones of activated faults, which are extremely mobile and connected with the deep parts of the earth's crust, react most extraordinarily to all of the geodynamic changes occurring in it. Although in different parts they have different level of modern seismic activity, nevertheless the individual faults controlling the development of the genetically united morphostructures (for example, the individual rift basins) must be considered potentially seismically active over their entire extent. Here the maximum intensity of the earthquakes (the potential seismicity) must be determined by the scales of maximum seismic dislocations detected at least in one section of the fracture zone, for the seismostatistics do not always or everywhere reflect the upper level of seismicity. However, in the cases of complex internal structure of the large basins and uplifts, the zones of activated faults separating them into different sections can have different seismic potential (for example, Main Sayan, Tunkinskiy, and the Obruchev faults).

The seismogeological materials available at the present time are permitting us to isolate 22 systems of the latest faults in the Baykal-Stanovoy zone, including more than 100 fracture structures (see Fig 106) undergoing modern seismic rejuvenation or carrying traces of paleoseismodislocations. All of these zones correspond to the above-enumerated common morphostructural and seismotectonic peculiarities of the activated faults; therefore below we shall present the characteristic of only two fracture systems typical of the Baykal-Stanovoy zone of intensive arch-block and riftogenic movements:

the well-known Primorskoye (Bruchev) fault which extends along the northwestern shore of Baykal in the Udokan system of activated faults in the northeast of the Baykal rift zone. Detailed descriptions of the majority of the faults in the mountain belt of Eastern Siberia are presented in the publications of recent years (Florensov, 1960a, b; ACTIVE TECTONICS..., 1966; SEISMOTECTONICS..., 1960a, 1975a, b; Solonenko, V., et al., 1971; Sherman, et al., 1973; and so on).

D. I. Shcherbakov (1951) proposed that the fault bounding the system of Tunkinskiy basins and the Baykal rift itself on the Siberian platform side be called the Obruchev fault. It is made up of a number of independent branches of the systems of faults -- Tunkinskaya, Primorskaya, Ol'khon and Northern Baykal (Florensov, 1960b; SEISMOTECTONICS..., 1968; Zorin, 1971).

The Tunkinskiy strike-slip fault (Fig 106, see Fig 102) is the general structure of the entire chain of Tunkinskiy basins. As the Cenozoic dislocation, it inherited the ancient suture formed in the Lower Paleozoic (Florensov, 1960a) or in still earlier ages. It is not excluded that this rejuvenation occurred in the Central to Upper Pliocene during the period of the most energetic downwarping of the bottoms of the depressions (Ruzhich, 1922). Being discontinuous, the Tunkinskiy fracture is made up of several sections, in the damping of which the mountain spurs occur (Nilovskiy, Yelovskiy) -- transverse and diagonal intrabasin commissures having a reduced section of Neogene-Quaternary series (Logachev, 1958). At the points where the main fault line bends, bunches of transverse and radial fractures appear (Florensov, 1960a).

By the observations of A. P. Shmotov (1972), east of Arshan the branch of the Tunkinskiy fault inherits the ancient (Tubotskiy) overthrust. It is traced from the Tsagan-Ugun' River from the Torskaya basin to the Tubota River valley through the Yelovskiy spur to the Kymgarga River and then to the northwest (see Fig 102). Between the Tunkinskiy bald peaks and the Yelovskiy spur the zone of ancient overthrust is morphologically expressed in the form of a linear chute-like depression running a distance of up to 15 km (see the vicinity of the Arshanskaya structure in Fig 102).

In the investigated region the ancient overthrusts are mapped at many places (see Fig 102), but the linear sinkhole in the relief is expressed only by the Tubotskiy overthrust. Inasmuch as it is located in the zone of contrast articulation of the intensely developing rift basins with their mountain border, there are grounds for considering that the morphological expression of the ancient fracture in the modern relief is obligated to its Cenozoic rejuvenation and conversion to the Tunkinskiy strike-slip fault. The highland scarp which replaces this sinkhole in the west and obliquely intersecting the ancient series on the slope of the Tunkinskiy Alps directly indicates the stepped sagging of the blocks in the vicinity of the Tunkinskiy fault (Shmotov, 1972; Solonenko, V., et al., 1971). The comparative youngness of the Tunkinskiy strike-slip fault is indicated by the fractures of the Pleistocene terraces in the vicinity of the health resort

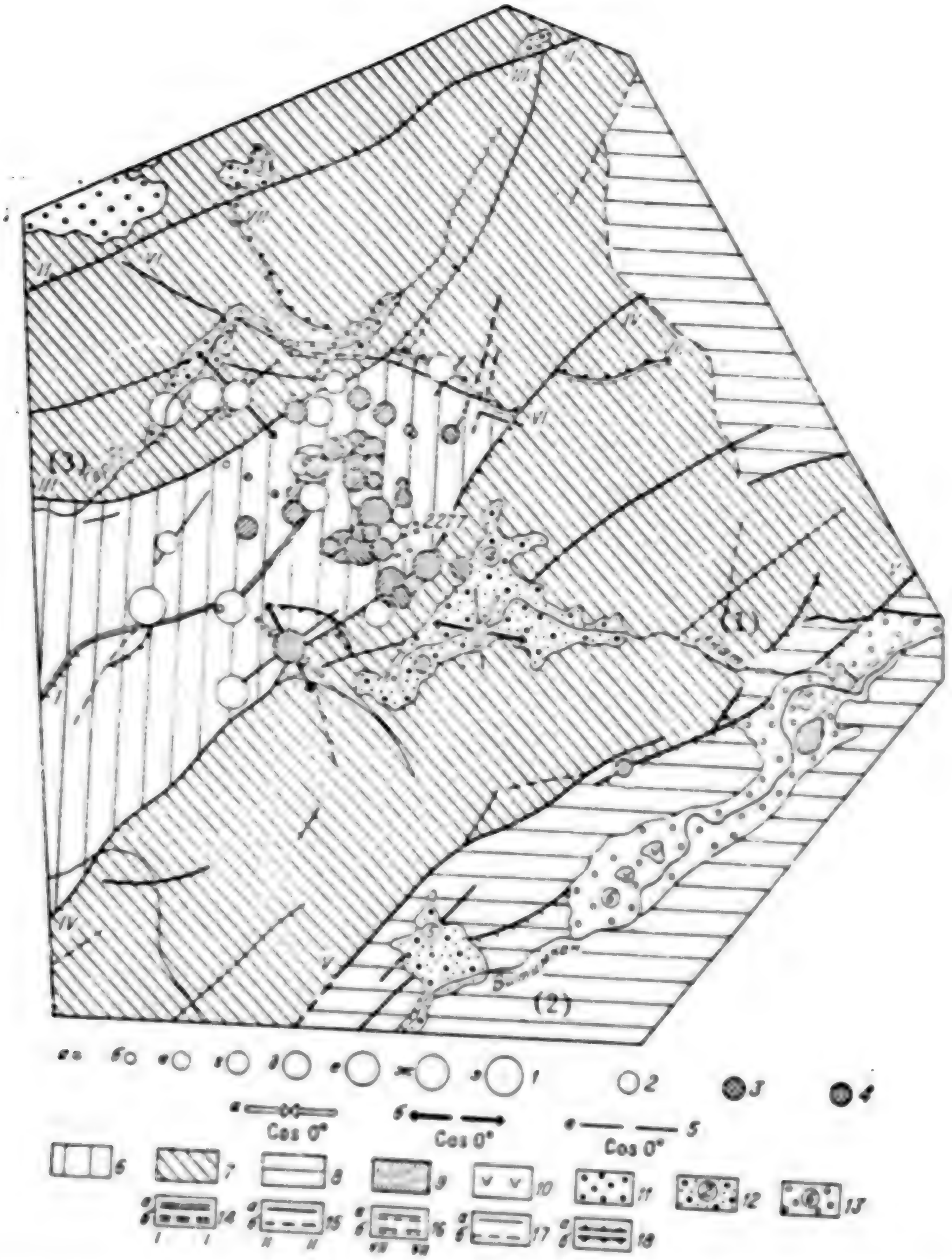

Figure 107. Schematic of the seismotectonics of the central part of the Ikatskiy [Ikat] arched uplift. Compiled by M. Dem'yanovich.
[See legend and key on p 331]

[Legend and key to Fig 107, p 330]:

Seismicity: 1 -- epicenters of the earthquakes with respect to energy masses -- K: a<7, b -- 7, c -- 8, d -- 9, e -- 10, f -- 10.5 to 11, g -- 11.5, h -- 12; 2-4 -- groups of earthquakes by the center mechanisms, 2--first group, 3--second, 4--third; 5--direction of stress axes,(a--compressive b -- tension, c -- intermediate). Seismotectonics: 6 -- most mob' e block of moderate uplift;

8 -- weak uplift, 9 -- projections of the basement in the basement of the transition type; 10 -- outcrops of Cenozoic basalts; 11 -- part of the Barguzin basin of the Baykal type; 12 -- embryonic basins (1 -- Marektinskaya; 2 -- Podikatskaya, 3 -- Marektakanskaya, 4 -- Verkhneikatskaya [Upper Ikat], 5 -- Dzhilindinskaya); 13 -- basins of the transitional (from Transbaykal to Baykal) type; 6 -- Vitimkan, 7 -- Nizhneikitskaya. The dislocations of the break in continuity: 14 -- seismically active: a -- established, b -- proposed (I-I -- Ulan-Burginskiy); 15 -- active in the Cenozoic (a -- established, b -- proposed); II-II -- Marektanskiy, III-III -- Garginskiy, IV-IV -- Dzhorgolanta-Nerungdinskiy, V-V -- Vitimkanskiy, VI-VI -- Ikatskiy; 16 -- Mesocenozoic (a -- established, b -- proposed): VII-VII -- Podikatskiy; 17 -- pre-Cenozoic (a -- established, b -- proposed),18 -- a) normal faults, b) overthrusts.

Key:

1 -- Ikat
2 -- Vitimkan
3 -- Garga

of Arshan and Yelovskiy spur, the triangular facies along the front of the Tunkinskiy bald peaks and the line of mineral springs at their foot (Florensov, 1960). Recent and modern seismic activity of the Tunkinskiy strike-slip fault is confirmed by the association of an entire series of epicenters of weak and strong earthquakes and also seismogenic structures with its zone.

The Tunkinskiy fault has feathering and accompanying fractures of significant extent. The southern branches of them are buried under the loose series of the basin (SEISMOTECTONICS..., 1968; Zorin, 1971). The morphological expression of some of them in the crystal bottom of the depression can indicate their Cenozoic activation. This pertains primarily to the largest transverse Kyngargskiy fracture which obliquely cuts the Tunkinskaya basin with respect to the Arshan meridian (Sherman, et al., 1973). The Irkut branch of the Tunkinskiy faults separating the mountain massif of Munku-Sardy Cape (absolute elevation 3493 meters) from the lowland western side of the Tunkinskiy bald peaks has clear traces of Cenozoic rejuvenation. One of the feathering fractures has a crushing zone of up to 200 meters. It is branched from the Irkut fault in the section near the fork of the Chernyy Irkut and Belyy Irkut Rivers. Extending along the northeastern

spurs of Munku-Sardyk mountain, the fracture is clearly expressed in the relief and has a strike to the northeast 70°. At an elevation of 2000 to 2500 meters the fracture is rooted along the chains of numerous landslips and also extended scarps and trenches (Shmotov, 1972; Solonenko, V., et al., 1971; SEISMOTECTONICS..., 1975a). On entering the Mondy basin, the Irkut fault branches. One of its branches is traced along the north side of the basin, the other, judging by the tectonic scarps, is well visible on the aerial photographs. It extends to the southeast to the foot of the Khamar-Daban ridge. The traces of the latest movements have been established predominantly in the northern foothill section of the basin. Beginning with Khara-Daban and to the western extremity of the Mondy basin, along the foot of the mountains there is a chute-like depression (strike azimuth 300°) from 100 to 300 meters wide which follows the Mondy-Khara-Daban ancient fault. Its recent rejuvenation is proved by a swath of modern streams and chains of small lakes (Shmotov, 1971; Solonenko, V., et al., 1971; SEISMOTECTONICS..., 1975a).

The series of rectilinear scarps and trenches up to 80 meters deep and up to 5 km long is observed in the mountain commissure between the Mondy and the Khoytogol'skaya basins. Intersecting, the riftogenic faults which break up this mountain commissure converge here, approaching from opposite directions. There is no doubt of the increased seismic danger of such sections (ACTIVE TECTONICS..., 1966; SEISMOTECTONICS..., 1968, 1975a).

On the left side of the Irkut River valley near Khara-Daban, the superposition and intersection of the ancient overthrust by the riftogenic joints is clearly observed, which demonstrates the neotectonic rearrangement of the structural plan existing here (Solonenko, V., et al., 1971; Shmotov, 1972; SEISMOTECTONICS..., 1975a). It was noted above that in the eastern part of the Tunkinskiy basin the fault with the same name follows the zone of the ancient overthrust.

In the vicinity of the eastern closure of the Torskaya basin, the Tunkinskiy fault has not been morphologically established. Between the Vystrinskaya [Vystra] and the Southern Baykal basins, the zone of the Obruchev fault also is not expressed in the relief, and in the Southern Baykal basin, the main route of this fracture has an underwater continuation.

The study of the underwater relief of the bottom of Baykal was undertaken by B. F. Lut (1961a, b, 1964) by the method of deep water echo sounding, which made it possible to discover an entire series of geomorphological peculiarities of the bottom of the lake caused by the neotectonics. In particular, the large, almost continuous extent of the sharply expressed sinuous underwater scarp around the west bank of the Southern Baykal basin was confirmed. The steepness of the deep water slope of the lake formed by the displacer surface of the Obruchev fault reaches maximum magnitude (60-70°) in the vicinity of Kolokol'nyy Cape. The gravimetric data interpreted by Yu. A. Zorin (1971) indicate the same thing, in accordance with which the Obruchev fault has an amplitude to 4000-5000 meters, and its displacer is

inclined in the direction of the basin at an angle from 50 to 90°. In the opinion of B. F. Lut (1964), a shallow water section adjacent to the Listvenichnyy Cape experienced block subsidence along the fault. The displacements of the blocks in the vicinity of the Obruchev fault were established in the underwater parts of the Primorskaya and the Krasnoyarovskaya seismogenic structures. The rejuvenation (possibly, historically, quite recently) of the Obruchevskiy fault has been proved by the fracture of the ancient Baykal terraces in the Slyudyanskaya Gulf and in the Tyya River delta (the northern part of Baykal). In the mouth of the latter, in the opinion of B. F. Lut, a section of the coast with sharply intersected ground relief was thrown under the level of the lake. The basic plane of the Obruchev fault cuts off a series of rocky capes such as Sagan-Maryan, Kovrizhka and Luvar' on the west bank of Baykal and Kamen' Baklaniy in the vicinity of Peschanoy Bay and shifts some in the direction of the lake. The volume of shifted rock massifs reaches 1 km^3 (Lamakin, 1955; Lut, 1964; Pal'shin, 1968).

According to the observations of N. V. Tyumentsev, in the vicinity of the village of Koty and the Goloustnaya River, the lake of parts of the small river valleys cut off and thrown into the depths of Baykal have been well preserved. V. V. Lamakin (1955) extended these observations to other sections of the west shore of Baykal.

The seismogeological investigations in recent years have demonstrated that in the recent historical past, the zone of the Obruchev fault was an arena of powerful earthquakes. It is coordinated with the Primorskaya and the Krasnoyarovskaya seismogenic structures formed during earthquakes with an intensity of no less than force 10 and having an underwater continuation (Lut, 1964; Khromovskikh, 1965). The Shartlay, Rita, Solontsovaya, Srednekadrovaya [Central Kadrovaya] and Khibelenskaya seismic structures of grand scale occurring during rejuvenation of the Northern Baykal branch of the Obruchev fault by underground shocks up to force 12 are located northeast of them. The echo sounding of the coastal zone in the vicinities of these seismic structures demonstrated the exceptionally complex structure of the lake bottom. Under the surface of the water in a strip up to 8 km wide gigantic blocks are hidden (up to 900 meters wide) -- erratic masses up to 150 meters high separated by graben-like depressions to 200 meters deep (Zhilkin, Pinegin, 1973). These are the frontal parts of the seismic structures with their characteristic swell-sinkhole relief. The more ancient seismostructures of Anga, Tonta, Sarma, Aral'skaya genetically connected with force 9-10 earthquakes are coordinated with the Primorskaya branch of the Obruchev fault which runs along the line of the mouth of the Bugul'deyka River to the Maloye Sea. This branch, although it enters into the Obruchev fault zone, in the Bugul'deysko-Malomorskiy section plays a secondary role in the rift formation, inasmuch as the amplitude of the vertical displacement along it does not exceed 200 meters (Zorin, 1971).

With respect to the set of geological-geophysical and seismogeological attributes in the vicinity of the Obruchev fault the following sections can be isolated with different seismic potential: 1. M=6.5-7;

I_0=force 9. The section of the Primorskiy fault between the southwestern closure of the Baykal basin and the Rita seismic structure, the section of the Northern Baykal fault north of the Khibelenskaya seismic structure and the Kich-rskiy fault, the Ol'khonskaya branch of the Obruchev fault.

2. M≥7; I_0=force 10 ore more. The Tunkinskiy fault, a section of the Northern Baykal fault between the seismic structures of Rita and Khibelenskaya.

In the vicinity of the southwestern closure of the Baykal depression, articulation and x-intersection of the Obruchev fault and the Cherskiy fault bordering the depression on the southeast takes place. The closure of them was established by echo sounding in the vicinity of Kultuk 10 km from the shore. Here the Obruchevskiy fault is split into a number of step faults with amplitudes of 700, 900 and 1200 meters. It is this characteristic "decay" that explains the damping of this powerful, extended fault dislocation in a very short distance (Lut, 1964).

Southeast of Slyudyanka, in the profile of the deep water slope of the lake the effect of a new structure begins to be felt -- the Cherskiy fault (see Fig 100). The amplitude of the fault scarps with respect to the direction from the coastal shallow strip in the direction of the lake water is 90, 180 and 300 meters (Lut, 1964). Then to the southeast the Cherskiy fault is traced in the form of an underwater scarp of 900 meters high gradually increasing to 300 meters (Ladokhin, 1957). The shifts along this fracture explain the inverse asymmetry of the lake pool in the section between Tankhoy and Mishikhoy. In general for Baykal coordination of the maximum depths with the western shore is regular. However, along the Cherskiy fracture the subsidence of the bottom of the basin takes place so intensely that it cannot be compensated for by the sediment accumulation (Lut, 1964). In addition, the uplifted wall of the fault here is incomparably more sharply dismembered by the underwater canyons which have occurred along the transverse and diagonal fractures (Voropinov, 1961; Ladokhin, 1957; Lut, 1964). They bound the horst and graben structures marked by high seismic activity.

On approaching the Selenga River delta, the Cherskiy fault is split into two independent branches. One of them runs into the internal part of the delta, and the other passes along the delta front. The morphological peculiarities of these fractures have been discussed in quite some detail in recent papers (Lut, 1964; Solonenko, V., 1964a; Khromovskikh, 1965; SEISMOTECTONICS..., 1968). On the periphery of the Selenga River delta there is articulation of the Cherskiy fault zone with the Goloustinsko-Kukuyskaya underwater structure (Lut, 1964), which is the intrabasin heaving of the crystal basement. In the bottom relief the Goloustinsko-Kukuyskoye uplift is in the form of two promontories up to 1000 meters high having northeastern orientation. One of them extends from the Kukuy Cape on the periphery of the Selenga River delta in the direction of the west bank along the traverse of the Goloustnaya River. An analogous promontory runs from the northeastern part of the Selenga River delta and wedges out into the central basin of Baykal.

This characteristic underwater ridge in structural respects is a one-way horst, on the east (frontal) side bounded by the fault, and on the west side, by the bend dislocations (Lut, 1961b, 1964). In our opinion, it is more logical to consider it the western boundary of the Obruchev fault zone. The northeastern continuation of the frontal fault of the Goloustinsko-Kukuyskaya morphostructure is the Selenga fault which enters into the Cherskiy fracture zone (SEISMOTECTONICS,..., 1968). The activity of this unique fracture is proved by numerous outcrops of thermal springs and the concentration of earthquake epicenters in the limbs of the Goloustinsko-Kukuyskaya structure. The northeastern branch (established amplitude 15 m) of the fracture was rejuvenated during the force 9 Central Baykal earthquake of 29 August 1959 (Solonenko, V., Treskov, 1960). The formation of the joint was accompanied by roiling of the water in the form of a linear belt of northeastern orientation. The other part of the investigated underwater morphostructure is formed by the tectonic step -- the uplifted western wall of the fault running from the Krestovskiy Cape in the direction of the Selenga River delta. The smoothed surface of the bottom of the lake traced from the mouth of the Bugul'devka River is broken here by a sharp scarp more than 150 m high (Lut, 1961a, 1963, 1964). According to the oral remarks of Yu. A. Zorin, these low-amplitude fractures in the crystalline basement cannot be recorded by the methods of gravimetry; therefore they are absent on the proposed structural diagrams (Zorin, 1971). This pertains on the whole to the entire Goloustinsko-Kukuyskaya morphostructure inasmuch as possibly a significant part of its uplift amplitude (800-1000 meters) is not connected with movements along the fault but is the result of the erosion-accumulative activity of the Selenga River in the frontal part of the formed delta against a background of general downwarping of the Baykal basin.

The uplift along the Cherskiy fault of the north limb of the Khamar-Daban arch in the latitudinal segment of the Southern Baykal basin during the Quaternary period hardly exceeds 250 to 300 meters (the maximum height of the Quaternary lacustrine terraces). The overall scale of vertical movements along this fault could reach maximum for the vicinity of the Southern Baykal basin with a magnitude that is on the order of 8000 meters. Up to 5000 meters of this in individual sections could be the "pure" amplitude of the Cherskiy fault.[1] In this case, the same law is retained as for the Baykal branch of the Obruchev fault: the maximum displacement along the fault decreases not in the ascending movements but in the descending movements of the blocks of crystalline substrate, and therefore these deep sutures more promote the formation of the basin than the positive morphostructures bordering it.

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[1]The amplitude of the background downwarping of the bottom of the Baykal basin undoubtedly reaches a significant value, but at the present time it is impossible to consider it quantitatively.

The Udokan fault system is predominantly a sublatitudinal system of neotectonic fractures occurring as a result of the involvement of the west flank of the zone of the Stanovoy deep suture in the process of rift activation (ACTIV. TECTONICS..., 1966). It runs more than 200 km primarily along the northern foothills of the Udokan ridge. However, a number of large fractures making it up (Namarakitskiy, China-Zakatskiy) are in the body of this arch-block uplift, controlling the development of the morphostructures of different orders.

In spite of the complex, branched plan configuration, the Udokan system of dislocations with a break in continuity is characterized on the whole by echelon structure predominantly with sublatitudinal and northeasterly strike of the individual echelon fractures 15 to 60 km long. Complexly differentiating the axial part of the rift zone, at the same time they define the development of the structures differing with respect to their morphogenetic peculiarities. Here the type, rate and direction of the seismotectonic movements, and accordingly, the level of the potential seismicity are different for the individual fractures and even sections of them. The highest seismic potential characterizes the fractures controlling the embryonic basins -- Namarakitskaya, Eymnakhskaya, Lurbunskaya, and so on.

The main fractures of the Udokan system are the Namarakitskiy, Konda-Eymnakhskiy, Dovachanskiy, Lurbunskiy, Emegachi-Kemenskiy and China-Zakatskiy (see Nos 82-87 in Fig 106).

The Namarakitskiy fractures located on the south limb of the Muya-Chara interbasin mountain commissure, running in the sublatitudinal direction (75°) from the Taksima River basin to the Durelag River. Along the entire extent (35 km) it is clearly expressed in the relief, controlling the south side of the Namarakitskaya embryonic basin.

The west flank of the fracture breaks down into parallel echelons. The northern echelon running about 12 km bounds the complexly differentiated bottom of the western part of the Namarakitskaya basin on the south. On the south limb of the fracture there is a block of the first stage of the uplift of the Udokan ridge with an absolute altitude of 1200 to 1300 m. The apparent amplitude of the vertical displacement along the fracture is approximately 500 meters.

The southern echelon 25 km long separates the first stage of the ridge and the bottom of the central and eastern parts of the basin from the high mountain, so-called Tundakskiy block uplifted to a height of up to 2500 m. The fracture extends here predominantly along the rear suture of the pedestal of the ridge and disappears into the right bank of the Purelag River. The amplitude of the vertical displacement reaches 800 to 900 meters. The displacer plane dips steeply to the north.

The west flank of the echelon which runs more than 10 km underwent Holocene rejuvenation. The deposits of the side moraines of the lake glaciation

and divide capes of the left tributaries of the Namarakit River were broken and displaced. The height of the fault scarp reaches 10 meters (the basin wall is downthrown).

In the west, in the headwaters of the Nerundakan River (the Taksima River basin) the south echelon is cut by the extended (more than 80 km) Taksima-Dzhilindinskaya fault zone (see No 81 in Fig 106) bounding the Kokarevskaya and Taksima basins on the southeast (see No 56, 58 in Fig 106). The zone is oriented in the northeasterly direction and on the east bounds both the block of the first stage of the uplift of the Udokan ridge and, apparently, the northern echelon of the Namarakitskiy fracture.

The epicenter of the force 10 to 11 Muya earthquake of 27 June 1957 (M=7.9, center depth 22 km) for which the rejuvenation was experienced by two echelons of the Namarakitskiy fracture was coordinated with the vicinity of the articulation of these faults (north almost completely and south extending 14 km). The seismogenic movement along the fault bore on the whole the nature of a left strike slip, and the ratio of the horizontal and vertical displacements was approximately 1:3 (ACTIVE TECTONICS..., 1966).

Thus, the Namarakitskiy fault is a clear example of the fracture structures causing the development of the embryonic basins for which, as was demonstrated above, the highest level of seismicity is characteristic. The combination of paleoseismodislocations, modern dislocations caused by the Muya earthquake and the extraordinarily active epicentral field in this fault zone makes it possible to define its maximum seismic potential as force 10 or more.

The Konda-Eymnakhskiy fault extending about 100 km has general sublatitudinal strike. It is located in the vicinity of the Muya-Chara interbasin commissure, participating in the formation of the Kuanda and the Eymnakhskaya embryonic basin. By its west flank made up of two parallel echelons of northeasterly strike, the fault penetrates deeply into the body of the Southern Muya arch-block uplift, complexly differentiating it into the positive and negative morphostructures of higher orders. On the west the latitudinal branch of the Muya-Tokko fault system departs from it, in this way realizing the connection of two regional lineaments. The narrow lowland commissure located between them is involved in slow subsidence, preparing the merging of the Muya and the Kuanda basins.

Farther to the east, the Konda-Eymnakhskiy fault in the form of the clear contrast fault scarp bounds the Kuanda basin on the south. The total amplitude of the vertical displacement reaches 1000 meters (without considering the plunge of the basement of the basin). A large thermal spring (T=+42°C) is associated with the fracture. The one-sided horst of the Namarakitskiy massif located on the south wall participated in the movements during the Muya earthquake of 1957, which is indicated by numerous surface deformations within its limits and the nature of the rupture of the tayga structures.

The east flank of the fault is broken into several parallel sublatitudinal branches expressed in the relief by steep scarps and controlling the morphostructure of the Eymnakhskaya embryonic basin. The Holocene volcanos and a number of mineral springs stretch to these faults. According to the geological and geomorphological attributes, the amplitude of the vertical displacements during the Quaternary time reaches 900 meters here.

In the central and western parts of the fault, sections of its fragmentary rejuvenation are directed (the tectonic deformations of the sand series of Middle Quaternary age and Upper Quaternary to modern proluvial deposits). During the entire period of instrument observations in the vicinity of the fault and especially on its western flank, high concentration of earthquake epicenters is constantly observed. Considering the entire set of attributes characterizing the seismotectonic activity of the fault, it is possible to consider that earthquakes with an intensity to force 10 are possible in the vicinity of it.

The Dovachanskiy fault branches from the Konda-Eymnakhskiy fault supposedly in the mouth section of the Purelat River, and it follows in the northeasterly (60-70°) direction along the Konda River, across the Dovachan Lake to the Lurbun River a distance of up to 60 km. In the section from the southwest flank to the Dovachan Lake, the fracture zone has the most complex structure. Here it is made up of several subparallel branches in which the erosion-tectonic Konda River valley is located. In the southeastern limb there is a block morphostructure, the part of which near the fault is deformed by numerous accompanying and feathering fractures forming the pologenic Dovachan seismic structure taken together (Solonenko, V., 1963; ACTIVE TECTONICS..., 1966). One of the sublatitudinal faults feathering the Dovachan fracture intersects the axial part of the block at a distance of more than 20 km (the southern fault-graben).

The overwhelming majority of the disturbances of the structure of ancient occurrence has the nature of faults, sometimes with left shift. Each of the fractures is characterized by a more or less steep, high scarp in the relief and is confirmed by the geological observations. The seismogenic movements of the Upper Quaternary and Holocene time occurred more than once along it. One such earthquake with an intensity of no less than force 10 occurred in the eastern part of the southern graben fault several decades ago, and the last earthquake (M=5.2) on 6 February 1975.

The long-preserved activity of the Dovachan fault zone, the traces of recent seismogenic rejuvenation and the high concentration of earthquake epicenters (especially in the southwestern part) permit estimation of its seismic potential at force 10 or more.

The Lurbunskiy and the Nizhneingamakitskiy faults are made up of series of sublatitudinal echelons connected by means of northeasterly shears into a united zone controlling the Lurbunskiy graben and the Ingamakitskaya embryonic basin from the south and southeast. Its total extent is 50 to 60 km.

The fault is clearly expressed in the relief by the steep (35-40°) fault scarps 500-800 meters high. Considering the thickness of the loose deposits in the basins, the total amplitude of the vertical displacement along it reaches 1000 meters. Here the maximum displacements (600-700 m) belong to the Upper Pleistocene to Holocene (500,000 to 600,000 years), which is established by the difference in elevations of the foot of the Lower Pleistocene basalt flow in the Ingamakitskaya basin and on the Stolovoy mountain. The last movements in the Lurbunskiy fault zone occurred no more than hundreds of years ago (the Nizhneingamakitskiy structure).

Considering the degree of intensity of the movements along the fault in the Late Cenozoic, the seismogenic mobility of the zone in the Holocene and the relatively high modern seismic activity, it is correct to consider that earthquakes can occur here with an intensity to force 10.

The China-Zakatskiy fault in the form of a single latitudinal linear zone is traced from the upper Ingamakit River to the Kalar River (about 90 km). In the west it is supposedly coupled with the system of riftogenic faults bordering the Lurbunskaya embryonic basin. Diagonally intersecting the Udokan arch-block uplift, it controls the neotectonic structure of the Upper Kalar subrift basin on the south here. In the east his fault merges with the activated zone of the Stanovoy deep suture.

The partial fractures making up the China-Zakatskiy fracture system has predominantly sublatitudinal and northeasterly orientation. In the vicinity of the sharp bend in the lower Ingamakit River and on the eastern flank, large feathering of fractures branch off it to the northeast (the northern branch and the Chepinskiy fracture). All of these tectonic disturbances are clearly expressed in the relief; the Late Quaternary movements along them frequently cause significant rearrangement of the geomorphological appearance and the hydrography of the territory.

On the west flank, the fault in the form of a scarp 10 to 15 meters high cuts the cover of the Udokan plateau basalts. The slag cones of the two Vakatskiy extinct volcanoes are directly coordinated with it. On the left slope of the lower Ingamakit River valley in the Chineyskiy gabbro-anorthosite pluton field, the fault is morphologically expressed by scarps 20 to 25 meters high, replacing each other in echelon form.

In the vicinity of the lower Ingamakit River where the northern branch separates from the China-Vakatskiy fault, the vertical movements along the fault have led to sharp rearrangement of the river network, as a result of which the headwaters of the China River have entered the lower Ingamakit basin. The subsequent erosion has obviously occurred using the gaping tectonic faults, and at the present time the lower Ingamakit River and some of its tributaries have deep rectilinear canyon-like valleys up to 1.5 km long and up to 100 meters.

East of the lower Ingamakit River, the basic route of the China-Vakatskiy fault is shifted somewhat to the south and acquires a diffe ent structure. In this section the fault bounds the China embryonic basin and is fixed on its south side by a chain of tectonic saddles and trenches, more rarely the steep scarps up to 4 to 5 meters high. In plan they represent a system of echelon type fractures from 1.5 to 5 km long.

On the east flank, in the vicinity of the upper Kalar subrift basin, the China-Vakat fault is discontinuous. Here, in individual sections of it the signs of fault and fault-shift displacements are noted. The amplitudes of the vertical movements reach 100-150 meters, and the horizontal movements, the first tens of meters. The sections of maximum plunging of the basement of the basin and active sediment accumulation are coordinated with the fault zone (the interfluve of the Solotov and the Doros, the Amudis Lake depression).

The material composition of the rock in the vicinity of the China-Vakatskiy fault indicates its ancient pre-Cambrian occurrence. The clear expression in the relief indicates the rejuvenation of the tectonic movement in the Quaternary time along it. The rejuvenation of the tectonic zone in the post-glacial period occurred in the flank sections. In the west the complex of residual seismogenic deformations with a total extent of 43 km (China-Vakatskaya paleoseismogenic structure) is supposedly connected with the pleistoseism region of the force 10 to force 11 earthquakes of 2 February 1725 (ACTIVE TECTONICS..., 1966). In the eastern closure of the upper Kalar basin the traces of the Holocene (first thousands of years) movements have been established in the vicinity of the Chepa fault (the paleoseismogenic Medved' structure). Thus, the seismic potential of the China-Vakatskiy fault zone is estimated according to paleoseismogeological data at force 10 or more. The epicenteral field of the last decade encompasses only the western part of the fault, and the rest of its path is almost seismically passive.

Transitional Morphostructures Between the Baykal Rift and Transbaykal Block-Wave Zones

Along the southeastern edge of the Baykal rift zone there is a characteristic set of morphostructural elements developing on interaction of the movements of the riftogenic and Transbaykal type. The farther from the axis of the Baykal rift, the less the rift stress field is felt, and the bending deformations have predominant significance in the development of positive and negative morphostructures. The outlines of the basins on the uplifts are blurred. Their articulation zones are smoothed; in the majority of cases the contrast is poor, and the fracture structures play a secondary role.

Among the positive morphostructures, the arched uplifts predominate. Here the large arches (for example, Khamar-Daban, Ikatskiy, Udokano-Kalar) have a complex structure. The frontal parts of the uplifts turned toward the rift structures experience sharp rearrangement, predominantly as a result of the descending (riftogenic) movements. As a rule, they are sharply differentiated, and on the seismotectonic level they approach the morphogenetic type of the arch-block uplifts of the Baykal-Stanovoy zone. At the

same time, orographically these sections are connected with large massive, weakly differentiated areas, the tectonic movements in which during the period of Mesocenozoic activation were manifested in the form of a slow, general rise causing predominance of bending deformations.

The negative morphostructures also have characteristic transitional developmental features, and on the whole they belong to the subrift basin type. These troughs with sharply diminished rate of downwarping and thickness of the Cenozoic deposits obviously exhibited activation simultaneously with the large riftogenic basins, but the process of their development proceeds much more slowly.

Let us consider the most characteristic examples of these transitional morphostructures.

Positive Morphostructures

The standard structures of this morphogenetic series are the arched uplifts of the Khamar-Daban and the Ikat ridges.

The Khamar-Daban ridge frames the Tunkinskaya and the Southern Baykal rift basins about 350 km to the south and southeast. With respect to its morphostructural peculiarities, it is nonuniform. The western and northeastern Khamar-Daban are characterized predominantly by the features of arched uplifts, and the Central Khamar-Daban,[1] by the arch-block uplifts.

On the whole, the ridge is asymmetric; the height of its top surface increases sharply from the direction of the rift zone, reaching 2200 to 2300 meters (maximum height 2758 meters). In the highest part of the uplift, sections of the volcanic plateau and Tertiary peneplain with gently sloping wavy relief were retained. These fragmentally retained relicts of the ancient denudation surface outline the arched uplift somewhat flattened in its axial section. Its maximum is coordinated with the central Khamar-Daban. However, the bending deformation first noted by V. V. and N. V. Lamakin has been best noted in the western Khamar-Daban along the slope of the lava plateau.

In general morphological appearance of the uplift of the Khamar-Daban ridge, the stepped nature of the relief has been poorly noted. This indicates insignificant participation of the latest faults in the formation of the arch and in its internal differentiation. The Baykal zone of the central Khamar-Daban where the Cherskiy fault has a noticeable effect constitutes an exception. Here, in the axial part of the uplift close to the Baykal

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[1]With respect to its morphostructure and seismotectonics, this part of Khamar-Daban essentially belongs to the arch-block structures of the Baykal-Stanovoy zone.

basin numerous seismogenic fractures are concentrated which are connected with the earthquakes of the recent past of force 10-11 (Solonenko, V., 1963a; Khromovskikh, 1965; SEISMOTECTONICS..., 1968). This zone of high-activity contains direct proofs of the growth of the Southern Baykal rift basin as a result of rupture of the highly uplifted part of the arched morphostructure by the descending (riftogenic) displacements of the individual blocks of the earth's crust. Here an important role is played not so much by the Cherskiy fault zone as by the faults feathering it having ground continuation in the form of fault scarps, obliquely intersecting the northern frontal part of the central Khamar-Daban.

Thus, in the investigated part of the arched uplift of Khamar-Daban the development process proceeds in the direction of sharp complication of its internal field. The high seismic potential, in addition to the numerous seismostatistical data, is confirmed by traces of the great seismic disasters of the recent past -- the Solzan, Badkha, Khara-Murin, Snezhnaya structures, and so on (Khromovskikh, 1965).

Accordingly, the potential seismicity of the frontal part of the Khamar-Daban arch turned toward the rift zone appears to be high, and it reaches a maximum (forces 9-10 or more) in the central Khamar-Daban. In the remaining part of the arched uplift, moderate seismic activity is noted, and the possible maximum earthquake strength is estimated at force 8 (K_{max}: 14).

The Ikat ridge downs the Barguzin rift basin from the southeast, and just as the Khamar-Daban uplift, it has inherited features of the ancient plateau (smooth forms of massive divides, broad development of the planation surfaces, and so on).

The outlines of the transitional boundary between the Ikat arched uplift and the Barguzin rift basin are sinuous and blurred. This nature of the pedestal zone of articular, the absence of the latest tectonic strikes in it, the soft and smoothed forms of the relief indicate that the bending deformations play the basic role here.[1]

On the whole, during the formation of the morphostructure of the Ikat arch the inheritance was manifested in predominance of the retarded general uplift which predominantly caused a flexible nature of deformations. Nevertheless, the frontal and axial parts of the uplift turned toward the rift zone experience complex block differentiation (see Fig 107) connected with the active development of the largest, latest fractures -- Garga, Argoda, Ulan-Burga, Marektakanskiy, and so on (SEISMOTECTONICS..., 1968). The lines of these faults clearly expressed in the relief are located at an acute angle to the strike of the Ikat arch and complicate the morpho-

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[1] In recent times the linera epicentral zone was discovered. S. I. Golenetskiy considers that it can be connected with the fault still not emerging at the surface of the earth (see Chapter VIII).

structure of its central and rift parts by the superposed block displacements. The noted faults of general northeasterly strike are expressed in the relief by erosion of tectonic scarps from 25-50 to 150-200 meters high extending several tens of kilometers. Some of them control the development of the embryonic basins -- Marektakanskaya, Podikatskaya, Verkhneikatskaya, Ulan-Burga. Thus, these latest faults, which have a local nature on the scale of the entire uplift cause the arch-block nature of its central part.

The seismotectonic peculiarities of this part of the Ikat arch are also connected with the complex block differentiation. Thus, in spite of the high modern seismic activity (A_{10} about 1.0), this territory is in practice free of traces of recent disastrous earthquakes; there are no macroseismic data about them since the beginning of the 19th century. It is true that some of the fractures clearly expressed in the relief (Ulan-Burga, Marektakanskiy, Argoda) sometimes carry signs of seismogenic movements occurring in them, but the sources of these movements obviously run deep into the Anthropogene. Of them the Ulan-Burga fault has the greatest significance for estimating the potential seismicity. In its vicinity earthquakes with an intensity to force 9 ($M \geq 7$) are possible. The same potential can be proposed also on the whole for the Barguza complexly differentiated part of the Ikat arched uplift. Along its periphery, along the fault zones controlling the development of the subrift basins (Verkhne-Turkinskaya [Upper Turkinskaya], Vitimkanskaya [Vitimkan]), structures have been isolated with which the connection of earthquakes of an intensity to force 8 (M=5-1/2 to 6-1/2) is possible. For the remaining territory of the Ikat arch (about 50% of the area), the occurrence of force 7 earthquakes is possible (M=4-3/4 to 5-1/2).

The sections with clearly expressed arch-block morphostructure of the Ikat uplift are distinguished by the constantly high modern seismic activity. Here the analysis of the numerous weak shocks and earthquake trenches have made it possible to discover the characteristic of the center zones separated in the section of the earth's crust with respect to the nature of the mechanisms (Misharina, Solonenko, N., 1972), which possibly reflects the "layered" nonuniformity of distribution of the stresses in the given section of the earth's crust.

Thus, the examples of the Khamar-Daban and the Ikat ridges indicate the nonuniform seismic potential of the arched morphostructures of the transitional type. The sections of riftogenic rearrangement of such inherited, long developing structures (modern basin formation, the "active" tectonic zone, activated faults, and so on) are most favorable for the occurrence of earthquakes with maximum intensity. In the evolution of the uplifts themselves these sections can indicate different stages of transition from "pure" (Transbaykal) arches to complexly differentiated arch-block structures of the rift zone. On the whole the level of the potential seismicity of the arch uplifts of the transitional type is moderate. The expected maximum strength of the earthquakes in the majority of cases will not exceed force 8.

Negative Morphostructures

The subrift structures (Selenga-Itantsinskaya, Verkhneturkinskaya, Vitimkan, Gorbylovskaya, Tsipakanskaya, Bauntovskaya and upper Kalar) occupy an intermediate position between the basins of the Baykal and the Transbaykal types (see Fig 100). On the other hand they have historical-genetic connection with the Transbaykal and on the evolutionary level (at least to the Pleistocene) they developed in a tectonic situation similar to them. On the other hand, beginning with the Pleistocene, the development of these transitional morphostructures received significant influence from the riftogenic movements, which is expressed in the intensification of their block differentiation, the involvement of the individual sections of the basins in active subsidence, seismogenic rejuvenation and the occurrence of the latest faults in their borders.

The basement of the subrift basins, by comparison with the rift basins, have been uplifted (absolute elevation 300 to 700 meters, sometimes to 1000 meters), and with respect to the Transbaykal, it has been downthrown by 200-400 meters. Considering the amount of plunging of the basement and the maximum absolute elevations of the Cretaceous-Paleogene planation surface (2600 to 2700 meters), it is possible approximately to determine the total amplitude of the vertical tectonic movements during the Neogene-Quaternary period of activation. It fluctuates from 1700 to 2100 meters for the region of different subrift structures. This is approximately 3 to 4 times less than in the rift structures themselves, and it exceeds by two times the scale of the displacements in the Transbaykal zone. This contrast of the tectonic movements as a whole agrees also with the velocity gradients (grad V $M=0.6\cdot10^{-8}$ to $1.0\cdot10^{-8}$), the values of which are much higher than the Transbaykal and lower than the rift. Thus, even this approximate analysis of the morphometric data makes it possible to describe the subrift structures as occupying an intermediate position between the Transbaykal and rift structures themselves.

The accumulation of 300-700 meter series of Neogenic-Quaternary deposits in the subrift basins indicates activation of the tectonic movements in the late Cenozoic. In a number of basins (Tsipa-Bauntovskaya system) the lower, thin part of the section is characterized by the Eopleistocene, predominantly lacustrine facies (the depressed molasses of orogenic formation). The accumulation of these finely clastic facies occurred under the conditions of the weak contrast relief. The intensification of the block movements, beginning with the Upper Pleistocene, the increase in the sediment accumulation rate caused sharp facies changes, at the same time, thicker polygenic series (orogenic molasses) are formed.

The upper Kalar basin is isolated from the overall system of investigated transitional structures (ACTIVE TECTONICS..., 1966; Vel'yanovich, et al., 1969). In contrast to the remaining subrift basins, it was involved from the Paleogene in intense uplifting and during the Late Cenozoic remained in practice inhert. This is indicated by the thin (to 100 to 150 meters)

discontinuous series of Quaternary deposits covering about 40% of the basin area. From the Pleistocene in the development of the upper Kalar basin some reactivation is noted connected with the block differentiation of the Udokan-Kalar uplift under the effect of the riftogenic movements. This was also felt in an increase in the seismotectonic activity, which is confirmed by the "reactivation" of the "Fedorovskiy" fault on the left bank of the Doros River and the paleoseismogenic Medved' structure formed during the earthquakes of no less than force 10. The seismostatistical material (during a decade of observations) with respect to the upper Kalar basin indicates its relative seismic passiveness: only individual earthquakes with $K \leq 10$ were recorded. However, it is not excluded that the seismic passiveness is apparent, occurring after the disastrous earthquake of 1725 obviously connected with the China-Vakatskiy fault (Solonenko, V., 1968b). The upper Kalar basin enters into the "zone of quiet" in the highly seismic region, and there are grounds for assuming that this zone is a "region of preparation" of strong earthquakes (Borovik, et al., 1971).

The subrift basins expanding the Baykal rift zone with respect to its southeasterly periphery is an additional element in the evolutionary series of negative morphostructures (Solonenko, V., 1968b; SEISMOTECTONICS..., 1968). With respect to age of Cenozoic activation and degree of morphological perfection, in the given stage of development they approach the mature basins of the Baykal type, but with respect to intensity of the riftogenic movements, they lag behind the majority of the rift basins.

The potential seismicity of the subrift basins, both with respect to seismostatistical and with respect to seismogeological data on the whole is significantly below the rift structures (M=4-3/4 to 5-1/2, I_0=force 7 to 8). However, in the vicinities of the faults bounding the individual basins (for example, the Bauntovskoy-Tilishminskaya and the China-Vakatskaya), the paleoseismogeological data indicate the possibility of the occurrence of earthquakes with an intensity to force 10 (the Tilishminskaya and the Medved' seismic structures, see Chapter VII).

Just as in the majority of rift structures, the intrabasin commissures have increased activity in the subrift basins. For example, in the Bauntovskaya basin on the Busano-Filinskaya commissure, a significant number of weak and moderate earthquakes are constantly recorded. A strong earthquake occurred here on 21 July 1968 (M=5.1; I_0=force 7). It was preceded by numerous foreshocks. The activity of the center was noted after the main shock: thus, in September-December 1969 an earthquake swarm was recorded here (206 shocks).

On the whole, the analysis of the structural-geological and seismotectonic peculiarities of the morphostructures of the transitional type indicates that their formation and development occurred under the effect of the tectonic stresses acting both from the direction of the Baykal rift and the Transbaykal block-wave zone. Here the effect of the rift stress field, beginning with the Pleistocene, became predominant, and in the Holocene, individual parts of the investigated morphostructures are completely involved

in the riftogenic type of development. Accordingly, the increasing influence of the riftogenic processes also caused increased (by comparison with the Transbaykal structures) seismic potential of the transitional type morphostructures.

Transbaykal Block-Wave Zone

The Transbaykal block-wave zone more than 60,000 km^2 in area occupies the southeastern part of the epiplatform orogenic belt. It is characterized by alternation of the low and medium mountain uplifts with basins of the Transbaykal type extended in the northeasterly direction, which on the whole causes an arch-block (block-wave) structure of this territory.

With respect to nature of the latest tectonic movements and the morphostructural peculiarities all of Transbaykal is broken down into three subzones: Selenga-Vitim (B_1), Khentey-Daurskaya (B_2) and Eastern Transbaykal (B_3) (see Fig 100.

The Khentey-Daurskaya subzone is represented by a high, weakly differentiated arch uplift. It was isolated as a first-order structure by N. A. Florensov, 1948) and Ye. V. Pavlovskiy (1948a). The two other subzones are large regions of relative subsidence (lagging in the uplift behind the Khentey-Daursskiy and Baykal arches), the internal parts of which are made up of positive and negative morphostructures of second and higher orders.

A characteristic feature of the neotectonic development of the Transbaykal as a whole is the predominance of the ascending type of movements (Khain, 1973). In addition to the qualitative analysis of the geological situation, this is confirmed by the quantitative calculation of the rate of the vertical tectonic movements. The rate of the ascending movements is approximately 5 times higher than the descending. For example, the average rate of rise of the Malkhanskiy arch-block uplift, judging by the deformation of the Miocene-Pliocene planation surface in 10 million to 20 million years reaches 0.1 mm/year. The mean subsidence rate of the Chikoy basin adjacent to this arch does not exceed 0.02 mm/year.

Another remarkable feature of the latest and modern development of Transbaykal is basically the inherited structural plan and type of development of it from the Upper Mesozoic tectonic regimen (Florensov, 1960b; Zorin, 1971; Yefimtsev, 1971). However, the inheritance features are not identical everywhere. They appear most clearly within the limits of the Selenga-Vitim subzone and the least in the Daurskaya and the eastern Transbaykal subzone.

Under the conditions of Transbaykal, the calculation of the gradients of the rate of vertical tectonic movements and satisfactory convergence of these data with the seismostatistics have made it possible to approach the determination of the level of the seismic potential both of the entire zone as a whole and its component elements, As a result of the calculations, the following series was obtained with values of the gradients: 1) from $1 \cdot 10^{-9}$ years^{-1} to $2 \cdot 10^{-9}$ years^{-1}; 2) from $2 \cdot 10^{-9}$ years^{-1} to $4 \cdot 10^{-9}$ years^{-1};

3) from $4 \cdot 10^{-9}$ years^{-1} to $6 \cdot 10^{-9}$ years^{-1} (see Fig 101). This series approximately corresponds to the zones with possible strength of the earthquake: 1) less than force 7; 2) force 7-8 and 3) force 8-9. This correspondence was initially established by us in the example of the central, and in part western Transbaykal (the vicinity of the Chikoy, Ingoda and Gusinoozerskaya basins), where seismostatistical and paleoseismogeological data are available. Then it was extended to the remaining sections of the territory of Transbaykal where the paleoseismogeological material is missing, and the seismostatistics are quite meager.

We shall discuss the specific estimate of the potential seismicity when describing the seismotectonic role of positive and negative morphostructures in Transbaykal.

Positive Morphostructures

The predominant position in Transbaykal both with respect to area and with respect to seismotectonic activity is occupied by the arched and the block-arched uplifts. With respect to mechanism of formation, these structures are quite similar, but for the second type, along with the bending deformations, the brittle deformations also acquire a noticeable role, playing a significantly lesser role than in the Baykal-Stanovoy zone. The characteristic of the development of the positive structures is presented in the papers by V. N. Danilovich (1960, 1963), N. A. Florensov (1960b; 1965), G. F. Ufimtsev (1971).

Let us present examples of the most characteristic Transbaykal uplifts.

The Malkhanskoye uplift is the standard arch-block morphostructure. The maximum height of the Malkhanskiy ridge is 1400 to 1700 meters; it is 270 km long with a width to 30-40 km.

The arch-block nature of the latest structure is emphasized by the nature of the deformation of the ancient planation surface, the relicts of which have remained at maximum altitudes in the axial part of the uplift and frequently in the limbs. The slope of the planation surface in the limbs of the Malkhanskiy uplift is 2 to 5°, and at the articulation points of the limbs of the structure with the intermontane basins, it exceeds 5°, creating the flexure-forming transitional zones (Ufimtsev, 1971). In the transition zone itself between the uplift and the subsidence structures are noted which are comparable to the forebergs (Gobi-Altay..., 1963). The extent of the structures is on the average up to 10 km, up to 3 km wide, the absolute elevations rarely exceed 1000 meters. Some asymmetry of the slopes of these promontories is noted. The spoke usually is greater in the direction of the ridge.

In various areas it is possible to see different stages of development of the forebergs. For example, the generating structures of the given type are observed. These are the individual low ridges made up of proluvial material of the Upper Pleistocene and younger age. The amplitude of the

relative uplift reaches 40 to 60 meters. The more mature form of these structures is the well expressed linear ridges extending up to 15 km with a height to 100 meters. They are made up of the dislocated Early Quaternary deposits. Finally, it is necessary to consider the mountain chain made up of rocks of the Paleozoic basement that are isolated from the basic mountain massifs and are collected by unity of strike with the "forebergs" of the preceding type. They extend up to 15 to 20 km, and the relative rises are 200 to 300 meters.

These three types of structures are different stages of their development and indicate successive involvement in the uplift of the lateral parts of the basins, which causes expansion of the positive structures at the expense of the adjacent negative ones. The Transbaykal type of structures are similar to the Gobi in this respect, and it distinguished them theoretically from the Baykal (Solonenko, V., 1968b).

The level of potential seismicity of the arch-block uplifts of the Malkhanskiy type, judging by the gradients of the neotectonic movements and the residual deformations (see Chapter VII, Yadrikhinskaya structure) is high among the positive morphostructures of Transbaykal and can reach force 8-9 at the limit (M to 5-1/2 to 6-1/2). This is indicated by the epicenter of the force 8 earthquake of 1934 (M=6).

In the general case the difference in nature of growth of such positive structures, their intensity, differentiation and stage nature causes fluctuation of the seismic potential of the Selenga-Vitim and the Eastern Transbaykal subzones from 7 or less to force 8-9.

Among the arches of the Transbaykal zone the best studied is the Khentey-Daurskoye uplift. In the investigated territory it is bounded by deep faults: Chikoy-Ingoda -- on the northwest, Onon-Turinskiy, on the southeast; Vostochno-Khangayskiy on the west, and Kukinskiy (supposedly according to the geological data) on the east. The width of the arch exceeds 150 km, and it is more than 400 km long. The maximum amplitude of the uplift fixed by the planation surface reaches 1700 to 1800 meters (the headwaters of the Chikoy and Chikokon Rivers).

The bending deformations with large (to 2400 km) radius of curvature (Ufimtsev, 1971) participate in the formation of the arch. The absence of large linear arch blocks will permit the assumption that in the initial stage of development of this structure no significant differentiated movements occurred. However, traces of weak latest tectonic movements with respec to the zones of individual fractures are quite numerous here. The ascending movements of the block are basically uniform along them. Some of them lag by 200-300 meters in the uplift.

Being developed in the latest time with inheritance from the Upper Mesozoic structural level, the arch nevertheless experiences constant growth with the exception of the northwestern part bounded by the Chikoy-Ingoda marginal

suture. Here, for example, the Altan-Kyrenskaya Upper Mesozoic basin turns out to be involved in the uplift. This basin which previously (in the Upper Jurassic to Lower Cretaceous) was at the foot of the arch, making up its southeastern boundary. The boundary of the arch after the Neogene-Quaternary period shifted about 35 km to the southeast, and at the present time it runs along the Onon-Turinskiy fault. The involvement of the adjacent sections along the northeastern periclinal arch, for example, Arshanskaya and Ureyskaya Upper Mesozoic basins proceeds analogously (Ufimtsev, 1971).

The noted peculiarity is also characteristic for the development of other arches of the Transbaykal block-wave zone. Seismically the most dangerous within the limits of such structures are the marginal parts of the arches (the limbs and periclinals).

Negative Morphostructures

The Transbaykal type basins occupy another seismotectonic position in the Transbaykal lump-wave zone (Florensov, 1960a). These are the geomorphologically expressed intermontane troughs (graben-synclinals) -- linear sections of plunging above the fault or next to the fault between the arch-block uplifts. The maximum length of them reaches a few hundred kilometers, and the width reaches 30-40 km (see Figures 100-104). The greatest thickness of the Mesocenozoic sedimentary series in the basins is 1600 to 1800 meters; of them about 200 meters are for the Pliocene-Quaternary sediments.

As the geological boundaries of the basins let us take the flexure forming transition zones along the marginal arcogenic overthrust (or upthrust faults) bounding the region of propagation of the lithofied sedimentary series. With respect o morphological and genetic attributes N. A. Florensov (1960a) includes only those slopes in the troughs which are converted to the sedimentary accumulation bed with completed layer formation. He includes the higher ablation region in the mountain border.

The outlines of the basins discovered in this way in general have smooth features, sometimes disturbed by sharp distortions connected, as a rule, with the folded disturbances and the dislocations with a break in continuity.

The basic structural elements of the basins are the trough-like depressions separated by the projections of the crystal basement reaching the day surface or covered with a thin veneer of Mesocenozoic deposits. In the large basins (Chita-Ingoda, Chikoy, Khilokskaya, Gusinoozerskaya) up to 3-5 troughs are observed separated by projections of the basement. These include the maximum thicknesses of the Mesocenozoic deposits.

In the modern relief the troughs are the lowest sections of the depressions occupied by the accumulative plains. In both cases their surface smoothly becomes the adjacent arched uplifts, and in other cases, it is emphasized by the erosion-tectonic scarps up to 300-400 meters high or more. In the section the troughs are asymmetric. The asymmetry of the basins finds reflection

in the zonality of different facies types of loose Quaternary deposits. According to the drilling data, entirely defined correspondence of it to the zonality of the Upper Jurassic to Lower Cretaceous deposits is established.

The general characteristic of the latest tectonics of the Transbaykal basins is the inherited plan and type of their development from the Upper Mesozoic tectonic cycle (Florensov, 1960a). It is also possible to talk about maintenance in the latest time of the Upper Mesozoic development rate. This is indicated by the comparative analysis of the sediment accumulation rates in the same basins as, for example, in the Chikoy basin the maximum thickness of the Upper Mesozoic series in the individual troughs does not exceed 1200 to 1400 meters (Vnukov, 1967). Considering that its accumulation has occurred during the period from the Upper Jurassic to the Lower Cretaceous (about 60 to 70 million years), the average sediment accumulation rate is approximately 0.02 mm/year.

The thickness of the loose Pliocene-Quaternary (10 to 12 million years) series in the same troughs does not exceed 150 to 200 meters (Khotina, 1966), that is, the average sediment accumulation rate is also about 0.02 mm/year, which by comparison with the sediment accumulation rate in the rift basins is almost 10 times less. Accordingly, many researchers are inclined to consider that the basins subside only relatively, lagging in the uplift behind the actively developing positive structures. The fact that in the latest and modern period they still experience weak plunge is indicated by the presented sediment accumulation rates.

Among the other general features characteristic of the Transbaykal basins, it is necessary to mention the reduction of their area as a result of involvement of the marginal parts in the uplifts.

Evaluating the seismotectonic peculiarities of the basin development on the whole, it is necessary to indicate their insignificant role in the determination of the level of seismic potential of Transbaykal. Their basic formation is due to the smooth submersion with insignificant intrabasin differentiation. Therefore the tectonic movements connected with the formation of the basins cannot be a source of strong earthquakes.

Activated Faults

In Transbaykal, the latest faults of northeastern strikes which are longitudinal with respect to the smooth morphostructures predominate. With respect to genetic type they belong to the upthrow faults or the arcogenic overthrust sometimes complicated by gravitational faults (Danilovich, 1966; Florensov, 1960a; Ufimtsev, 1971).

The latest and modern movements along these faults are basically connected with growth of the positive structures. In some cases they are the interfaces between the positive and negative first-order structures

(Mongolian-Okhotsk and Dzhida-Vitim faults), and in others, of second and higher orders (Khilok-Karenga, Tugnuvskiy, and so on).

The individual faults from 20 km or more located parallel to the continuation of each other or substituted in echelon form, form separate systems with different level of activity. The width of such zones reaches 20 to 40 km, and sometimes more. The total maximum amplitude of the vertical displacement with respect to the individual faults during the Pliocene-Quaternary is 300 to 400 meters, and possibly more (Khotina, 1966; Ufimtsev, 1971).

As an example let us discuss the characteristic of two fault zones -- Mongolian-Okhotsk and Khilok-Karenga separating the first and second order structures respectively.

The Mongolian-Okhotsk fracture extends to Transbaykal from the territory of Mongolia and in the northeasterly direction, across the headwaters of the Nyukzha River, it runs almost to the Sea of Okh[illegible]. Its total length is up to 3500 km (in the regionalized territory, 1[illegible] km, and the width of its zone is from 20 to 40 km.

The fault is the boundary between the subzones -- the Selenga-Vitim (B_1) in the northwest and the Khentey-Daurskaya (B_2) in the eastern Transbaykal (B_3) in the southeast (see Fig 100).

The fault deforms the ancient Cretaceous-Paleogene and younger Miocene-Pliocene planation surface. The total amplitude of the vertical displacement of these surfaces with respect to individual faults in the zone during the Pliocene-Quaternary time reaches 300-400 meters. The modern activity of the Mongolian-Okhotsk fault is confirmed by the association of the epicenters of the strong earthquakes of force 11 and 12 with it (M=8.4 and 8.7) on 9 and 23 July 1905, and force 8 in 1934, force 7 in 1935, and so on.

The fault zones in the investigated territory include six individual elements. Their potential seismicity, judging by the paleoseismogeological data, seismostatistics and the magnitude of the velocity gradients of the vertical tectonic movements reaching $(4-6)\cdot 10^{-6}$ years^{-1}, decreases from force 8-9 in the west (the Chikoy element) to force 7 and less in the east (the Shilka element).

On the whole, a general decrease in the potential seismicity of the individual elements of the Mongolian-Okhotsk fault is noted from southwest to northeast.[1]

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[1] Beyond the eastern edge of our map (in the vicinity of the Tukuringro-Dzhazda anticlinorium) it again increases at least to force 8 (M to 6 and, possibly, more).

The Khilok-Karengskaya system of faults in the latest structural plan is the boundary between the positive and negative second-order structure, entering into the Selenga-Vitim zone. The extent of the system from the southwest to the northeast is up to 700 km with a zone width to 20 km. The mean length of the individual faults making it up is 120 km.

With respect to genetic type, these are basically upthrow faults or arrogenic overthrusts. The amplitude of the vertical tectonic movements along them during the Pliocene-Quaternary period is more than 200 meters (Khotina, 1966; Ufimtsev, 1971).

The low seismic activity (A_{10}=0.02 and lower), absence of paleoseismogenic structures, the low magnitude of the velocity gradients of the vertical tectonic movements not exceeding $3 \cdot 10^{-9}$ $years^{-1}$ indicates that the maximum level of the seismic potential of the individual faults in this zone is no more than force 7-8 (appreciably lower than for the faults of the Mongolian-Okhotsk zone). The other fault zones bounding the second-order structures do not exceed this level.

A comparison of the seismogeological data with respect to the characterized faults zones of different order confirms the existing opinion that the regional disturbance zones which bound the large structures having different speeds of movement are the most seismic. In addition, the opinion of the united seismic potential of the fault zone enters into contradiction with the actual material here.

Basic Laws of Seismotectonic Development

The above-described neotectonic and seismotectonic elements of the Siberian Cenozoic platform in the epiplatform orogenic belt provide important material for determining the nature of the movements of the earth's crust for the genetic varieties of morphostructures and the conditions of manifestation of the earthquakes. The seismotectonic process in many aspects follows the laws of tectonic development which were laid down in the Cenozoic for the Baykal-Stanovoy zone and in the Mesozoic for Transbaykal.

There is a contradictory opinion about the evolution of the rift process. In particular, it is considered that compression takes place from the Siberian platform side to the east (Groswald, 1965) or to the southeast (Dumitrashko, 1952; Azhgrrey, 1960; Voronov, 1964), tension to the southeast (Florensov, 1960a; Zorin, 1971) and to the northwest as a result of shoving of the platform back (Van Bemmelen, 1960) or combination of tension with horizontal displacement along the faults (Lamakin, 1968). Without discussing the advantages and disadvantages of each hypothesis, let us note that now the predominance of the tensile stresses across the strike of the neotectonic structures of the Baykal rift zone is generally recognized. Accordingly, the most probable and well-founded is the system proposed by N. A. Florensov, (1970) supplemented with respect to seismological and geophysical studies (Misharina, 1965, 1972; Zorin, 1971).

The analysis and the statistical processing of the data on the age of the surface planation for Eurasia as a whole (Timofeyev, 1965, 1968, 1969) indicates that a trend is observed toward the rejuvenation of the denudation plains from west to east. Thus, for the orogenic Central Asian belt the age of the initial plain varies from Triassic in the west to the Cretaceous-Paleogene in the east. This confirms the sequence of the tectonic activation in the latest time which began much later in Pribaykal'ye than in Western Asia (Petrushevskiy, 1964). The conclusion that the rift process is continuing to develop toward the east agrees with these principles and the Baykal rift zone is at the present time expanding its distal and lateral boundaries (Solonenko, V., 1968b, c; Florensov, 1970).

One of the clear indexes of growth of the rift zone is the continuing development of the embryonic and the generated basins (including the satellite basins) on the slopes and in the axial parts of the bordering uplifts. On the southwestern flank of the Baykal-Stanovoy zone the small basins have already lost the capacity for further development (Florensov, 1960a), and the activity of the peripheral seismogenic structures in the Upper Pleistocene-Holocene has been decreased significantly. The development in time of the beginning of the neotectonic movements between the southwestern and northeastern ends of the rift structures is also noted. If for the Baykal and the Tunkinskaya basins the maximum intensity of the Neogene-Quaternary activation belongs to the Miocene-Pliocene, then in the Stanovoy Highland it belongs to the Pliocene-Pleistocene (ACTIVE TECTONICS..., 1966; SEISMOTECTONICS..., 1968). D. V. Lopatin (1972) arrives at the same conclusion on the basis of analyzing the geomorphological data with respect to the eastern part of the Baykal mountain region.

The trend toward rejuvenation of the processes of reworking of the earth's crust on moving from west to east finds confirmation also in the manifestation of the effusive activity. Whereas in the southwestern flank the maximum manifestation of volcanism belongs to the Oligocene-Pliocene (Obruchev, 1950; Florensov, 1960a, Florensov, et al., 1960a) and the eastern flank the beginning of the eruptions belongs to the Pliocene-Pleistocene or Lower Pleistocene (ACTIVE TECTONICS..., 1966; Logachev, 1968; Lopatin, 1972).

In connection with the problem that has been touched on regarding the possible relation of the Neogene-Quaternary volcanism to the evolution of the rift structures it is necessary again to emphasize (Florensov, 1960a; Solonenko, V., 1964b, 1967; ACTIVE TECTONICS..., 1966; Florensov, et al., 1960a), that the direct relation of the volcanic processes to the zones of activated faults has not been established anywhere in the investigated region. On the contrary, even the Holocene, well-preserved volcanic apparatuses and the basaltic dikes (Udokanskiy, Khamar-Daban, Oka volcanic regions), to say nothing of the more ancient ones, do not have defined structural control on the part of the riftogenic faults. They are associated with the structural lines, as a rule, which obliquely the discontinuous elements of the rift structures or they are far to the side of them (Vitim and Oka plateaus). This noncoincidence of the strike of the volcanic zones (SV-30-50°) and the riftogenic faults (sublatitudinal orientation) is

especially clearly noted in the Udokan volcanic region (Solonenko, V., 1964b; ACTIVE TECTONICS..., 1966).

On the neotectonic level, the nature of the volcanism reflects the process of the latest activation on moving to the northeastern flank of the Baykal rift zone (Solonenko, V., 1968b, c). However, the actual relations of the volcanic and the riftogenic, frequently spatially combine and synchronously occurring processes, remain unclear and, most frequently of all, if they occur, then only in the most general form. Accordingly, in the seismotectonic aspect there is no defined or direct relation between the volcanic regions and the epicenters of strong earthquakes. Nevertheless, in a number of cases (for example, the Holocene volcanoes of the Udokan region) local epicentral fields and swarms of weak earthquakes are noted which extend spatially to the individual groups of volcanoes. It is possible that in these cases we are dealing not with tectonic, but volcanic earthquakes (Solonenko, V., 1968c), the more so in that the "suppression of the volcanic eruptions in the Holocene is possibly only a temporary phenomenon" (Florensov, 1960a).

The above-enumerated examples clearly indicate the rejuvenation of the tectonic processes from west to east. Accordingly, the proposition of V. P. Solonenko (1968b) regarding the migration of the rift stress field to the Stanovik region remains valid. However, this finds co[illegible]rmation also in the geophysical field in which the regular decrease in ab[illegible]te values of the gravitational anomalies above the basins from southwe[illegible] to northeast of the Baykal rift zone is noted which, together with an in[illegible]se in the overall level of the gravitational field is in accordance wit[illegible] the conclusion regarding migration of the rift formation to the east.

The studies of the mechanism of the earthquake centers performed by A. V. Vvedenskaya (1961) and especially in detail by L. A. Misharina (1965, 1967, 1972) demonstrated that the earth's crust within the limits of the Mongolian-Baykal seismic belt experiences the effect of the horizontal tensile forces oriented across the strike of the basic neotectonic structures, and the compressive stresses are steeply inclined (more than 45°) or they are close to vertical. The orientation usually corresponds to the strike of the morphostructures.

Previously it was considered that on the southwestern flank (Tunkino-Kosogol'skiy sector) the orientation of the stress axes is directly opposite. The inversion of the Baykal tectonic field was explained by the growing effect of Central Asian stress field. However, the detailed studies of recent years demonstrated that the stresses are summed up here which are connected with the riftogenic and the mountain-forming processes of the Mongolian (latitudinal) and Sayan (northwestern) directions which are still complicated by the directions of the tension (decay) in the highly uplifted blocks of the earth's crust.

Accordingly, the different earthquakes, even with close centers, can have a different mechanism which is confirmed by the analysis of the mechanism of the weak earthquake centers. Previously "it appeared that in the Tunkinskaya basin and to the west, the near-horizontal tensile stresses acting across the rift structures were being replaced by compressive ones. This idea has not been confirmed, and all of the conclusions regarding the modern direction of the tectonic movements of the earth's crust based on it have no basis" (SEISMOTECTONICS...., 1965a, p 128).

On the eastern flank of the rift zone, some specific peculiarities have also been discovered in the mechanism of the earthquake center. For the center of the Zverevskiy earthquake of 15 June 1971 (56.28° north latitude, 123.66° east longitude, M=5.9, H=15 km), the subhorizontal orientation of the axes of the tensile and compressive stresses has been established, although their spatial position with respect to the structures is analogous to that in the Baykal rift zone.

The migrational process of related activation in connection with the rift formation reached the vicinity of Central Olekma, in the individual riftogenic structures (Imangro-Chebarkasskiy graben and Kudulikanskaya generating basins) are coordinated with the west end of the Stanovoy arch. The plan differentiation of the intensity of the riftogenic process is confirmed not only by the magnitude and the size of the grabens, but also by the thickness of the molassoid formations filling the basin. Whereas in the Chara and other loaded roofed basins it is 1000 to 2000 meters or more, in Tokko basin, about 500 meters, and in the small basins of the Baykal type (embryonic and generating), appreciably less -- tens and a few hundreds of meters. At the same time the modern activity of the dislocations with a break in continuity controlling these structures is comparable or even higher for the small basins by comparison with the Baykal rift zone. The morphological damping of the rift structures on the east flank of the Baykal rift zone is combined with intensification of the general stressed state of the earth's crust. In particular, the basic number of paleoseismodislocations and strong earthquakes in the rift zone of the Stanovoy Highland stretches to the morphostructural complexes in which the small basins are developing.

In establishing the seismogeological relations and the seismotectonic peculiarities, the principle of inheritance has important significance. It was developed by N. S. Shatskiy (1938) as applied to the defined tectonic structures.

By this term we meant three interconnected aspects -- inheritance of the tectonic plan, tectonic forms and tectonic movements.

The Baykal rift zone has during its development to the east cut across the strike of in practice all of the pre-Cenozoic structural complexes. These problems have been investigated in considerable detail previously (Florensov, 1960b; Solonenko, V., 1968b; and so on), and the conclusions drawn convincingly indicate the superposed nature of its development.

The rift structures are newly formed, and their origin obviously is connected primarily with the dynamics of the mantle processes.

At the present time there is a possibility for tracing the structural evolution of the earth's crust from the Mesozoic in close connection with the tectonic stress field. The dislocations with a break in continuity bounding the Mesozoic and Cenozoic negative structures are indicators by means of which it is possible to determine the direction of the compressive and tensile forces and their change in time. Beginning only with these conditions, we can state to what degree the latest structures inherit the development of the preceding ones, for the replacement of the stress field leads to inversion of the sign of the movement of the individual tectonic elements of the crust. The formation of the Mesozoic basins and troughs bounded by the upthrow faults and overthrusts is closely connected with the predominance of the compressive stresses across the morphologically expressed structures.

The majority of discontinuous dislocations of this time connected directly with the tectonic field have sublatitudinal strike, orthogonal to the compressive stresses. As examples confirming this phenomenon we have the upthrow-overthrust faults, spatially and genetically connected with the origin of the Kalar, Khanivskaya, and Kudula tectonic depressions and the Chul'man trough. If we consider the series of overthrusts, including the Angara associated with the back of the Siberian platform of the same name, then it is obvious that the compressive stresses do not have a local, but they had a regional nature. It is true that in the vicinity of the Angara outcrop the compression structures are significantly smaller with respect to scale than those within the limits of the Aldan shield, and the age of the former is somewhat more ancient: at least the sedimentation cycle here ended in the Middle Jurassic, at the same time as in the Chul'man trough it continues even in the Lower Cretaceous. Obviously this is a consequence of the gradual weakening of the tectonic mobility from west to east in the Mongolian-Okhotsk belt (Nagibina, 1963; Komarov, 1967).

Beginning with the history of the geological development of the southern part of the Siberian platform in the Mesozoic, we can say that the tectonic field was characterized by the meridionally oriented subhorizontal compressive stresses and the sublatitudinal tensile forces steeply inclined toward the horizon, and thus, in turn, determined the nature of the dislocations with a break in continuity and the structures connected with them.

The Baykal rift zone, sometimes following the ancient dislocations with a break in continuity as weakened zones of the earth's crust, is developing in general features independently of them and has its own specific features of tectonic development differing from the preceding stage. This is primarily expressed in the fact that it was formed during the predominant stress role across the strike of the morphologically expressed grabens (Florensov, 1960a, 1970) in combination with the horizontal movements (Solonenko, V., 1960a, 1968b) with respect to the riftogenic faults.

Comparing the preceding (Upper Mesozoic) field of tectonic stresses and the modern one, we see that the orientation of the stress axes in them is diametrically opposite; the genetic type of the dislocations of the break in continuity and the nature of the movements along them are different, and correspondingly, we do not have any grounds for talking about the inherited development of the Baykal rift zone with respect to the preceding phase of tectogenesis.

The processes of modern activation of the western part of the Stanovoy ridge have found their expression in the deep erosion, the rearrangement of the hydraulic network and also in the formation of a number of discontinuities in the divides and on the slopes of the Zverev ridge expressed in the relief. Along the axial line of the latter, almost over its entire extent there is a fault expressed in the form of a steep scarp. The formation of this extended (60 km) fracture in the apical part of the arch-block uplift possibly represents the process of inversion of the tectonic movements in connection with the placement of the stress field. A similar process obviously has occurred at the location of the Chul'man Mesozoic trough which at the present time participates in the regional uplift of the southern part of Siberian platform and is a standard inverted morphostructure. The change in stress field, just as the side of the tectonic movements was caused by the effect of the neotectonic processes in connection with the development of the Baykal rift system. It is entirely possible that at the present time in the vicinity of the Stanovoy ridge the stresses of the Baykal type predominate, and the process of complete inversion of the Mesozoic field of tectonic stresses has occurred correspondingly, and the stress field of the Baykal type is developing farther to the east.

The deep faults have since the time of their formation usually represented active structural elements of the earth's crust, in connection with which they usually are considered structures of inherited development. However, it is impossible not to take into account the fact that from period to period, the type, the rate and the nature of the movements along them have changed, just as their magmocontrolling role has not been constant in time. During the periods of predominant compression the penetration of the magmatic melts in large volumes has low probability, and during the period of tension, the situation is more favorable for penetration of the deep, basic and ultrabasic differentiates of the magma (Peyve, 1965; Sherman, 1966; Florensov, et al., 1960a). The formation of the tectonic structures is directly connected with the tectonic stress field depicting, in turn, the mantle processes.

Thus, considering the development of the Baykal rift zone, we must again emphasize that it has developed superposed with respect to the more ancient structural plan.

Transbaykal, on the other hand, is characterized by relatively low level of seismic activity and moderate rate of neotectonic movement. The tectonic regime here is caused by the predominant development of the modern structural forms from the more ancient ones. This point of view was

stated by N. A. Florensov (1960a), and it was confirmed during further research.

The predominant type of latest and modern tectonic movements for Transbaykal must be considered to be the ascending one. Here the most active growth is experienced by the arches and the arch-block positive structures involving the lateral parts of the negative structures in the uplift.

As a result of the studies of the centers of strong and weak earthquakes (Misharina, 1965, 1967, 1972; Misharina, N. Solonenko, 1972), in addition to the horizontal orientation of the tensile stresses, the orthogonalness of them with respect to strike of the main neotectonic structures was also discovered. This conclusion is in accordance not only with the general geotectonic ideas of the riftogenic structures, but also with the seismotectonic observations in the epicentral zones of the majority of strong earthquakes in the past (paleoseismodislocations) and modern times.

Thus, the mechanism of themovement of the earth's crust during the Muya earthquake of 1957 established with respect to the seismic dislocations agrees quite well with the orientation of the stresses in the vicinity of the center (ACTIVE TECTONICS..., 1966). In the centers of the Nyukzha and the Olekma earthquakes of 1958, the stress orientation also corresponds to the situation and nature of the discontinuous deformations in the epicentral zone, which are tension joints of sublatitudinal orientation with insignificant component. This nature of the deformations corresponds to the meridional tensile stresses noted for the centers of these earthquakes.

The determinations of the mechanisms of the centers of the latest strong earthquakes -- Tas-Yuryakhskiy 1967 and Kadar 1970 -- confirm the presence of the tensile stresses oriented orthogonally to the main structural elements of the Kodar-Udokan and Stanovoy zones.

The studies of the stresses at the centers of the weak earthquakes (K=10-11) performed by L. A. Misharina and N. V. Solonenko (see Chapter V) indicated that even for them, in the majority of cases the rift orientation of the stress axes discovered by observations of stronger shocks is characteristic.

This indicates that the predominant type of surface deformations here must be the tension joints combined with the faults which can be accompanied by shifts. The surface deformations naturally are not a direct reflection of the processes, but at the same time the types of latest structures and also their spatial orientation are in accordance with the nature of the stresses in the center zones.

Thus, the modern stress field discovered by the seismic observations in the Baykal-Stanovoy seismically active zone agrees with the peculiarities of the stressed state of the crust in this region established by the geological characteristics. The stressed state of the earth's crust

remains in general typically "rift" even in the bordering part of the Stanovoy ridge, which indicates migration of the riftogenesis process to the Stanovik zone, causing higher potential seismicity on it (ACTIVE TECTONICS..., 1966; Solonenko, V., 1968b, c).

CHAPTER XII. SEISMIC REGIONALIZATION

Seismic regionalization by the earthquake force estimates has been criticized for many years. It has been proposed that it be replaced by regionalization with respect to quantitative characteristics (seismic accelerations and their spectra, the duration of the oscillations and their amplitudes, and so on).

However, these proposals, which are outwardly tempting, especially for calculating structural earthquake proofness are isolated from the actual natural situation, the possibilities of the equipment, the level of development and "density" of the seismological observations. They are frequently based on representations o. earthquakes at the earth's surface "by analogy" or on purely theoretical and not true manifestations which can be discovered only by investigating strong earthquakes.

Our experience in investigating earthquakes of all force levels (from 5-6 to 12) in the Mongolian-Baykal Seismic Belt and objective data from investigating earthquakes in other seismic zones of the earth indicate that sharp (to force 2-3 frequently, force 6-7 sometimes) variations of the seismic effect on the ground and structures are observed at short distances of up to 3 to 5 meters (Solonenko, V., 1960c, 1962a; Solonenko, V., Treskov, 1960; GOBI-ALTAY..., 1963; Solonenko, V., 1974). The investigators of the San Fernando earthquake of 9 February 1971, emphasized that the "tremors and destruction frequently were distributed over the area in a highly unexpected way, in connection with which the problem of seismic regionalization appears to be much more complicated than was assumed" (Gillete, Walsh, 1971). These phenomena have been encountered by the investigators of the Peruvian earthquake of 31 May 1970, who established that often there is no obvious relation between the intensity of the destruction, the basement material and the engineering-geological conditions. "We cannot explain all these phenomena," they conclude (Plafker, 1971a).

In addition, it is necessary to consider the following:

1. The effect of earthquakes on the ground surface and the structures varies sharply and theoretically on going from 5 to 6 and especially from force 9 to 10 when the reversible and residual deformations of the surface, the ground and the earth's crust with amplitudes to several meters established the limiting possibility of building earthquake-proof structures (Solonenko, V., 1960a, 1962a, 1974).

2. The quantitative parameters, for example, of a force 9 local earthquake cannot have almost anything in common with such force 9 tremors as the "transit" ones (from the zone of a strong earthquake of force 10 or higher).

3. The instrument characterization of destructive earthquakes (more than force 8) is faced with equipment and many other barriers (the possibility of obtaining recordings of epicentral and "transit" earthquakes of equal intensity in close areas with different engineering-geological conditions, and so on).

Thus, in order to obtain a true quantitative characteristic of earthquakes, it is necessary in essence to have a mass of seismometric equipment.

If we consider what has been said objectively, it becomes clear that the problem of "quantitative" general seismic regionalization will be solved only in the distant future if it is solved at all.

During microseismic characterization of earthquakes, the level of the seismic effect is averaged both as a result of the number of observation points and as a result of consideration of various factors. Thus, the "force" estimate is found to be significantly more meaningful than it appears to the proponents of the "quantitative" seismic regionalization, and it offers the possibility of designing actually earthquake-proof structures. For example, in Irkutsk on 29 (30) August 1959, during an earthquake the intensity of which was approximately the same as over the greater part of Tashkent in 26 April 1966, the buildings with force 8 antiseismic construction sustained only light damage in individual cases at the same time as almost all the old-style buildings, smaller and with thicker walls and foundations made of high-quality building materials, were deformed and often significantly (Solonenko, V., Treskov, 1960).

Thus, there are still nothing to replace the "force" concept (in the foreseeable future). The investigation of many strong earthquakes, wherever it has been done by objective investigators, indicates that the MSK-64 scale (Merkalli-Kankani-Ziberga-Medvedeva-GEOFIAN-GOST) gives a highly reliable determination of the intensity of the tremors and agrees quite well with the values of M and K (see Table 2). On this scale the dimensions of the residual deformations of the ground are essentially low, that is, by these signs it gives a high force estimate.

The relation between the force and the magnitude established empirically by the results of investigating strong earthquakes in the Mongolian-Baykal Seismic Belt (SEISMOTECTONICS... 1968, page 147) was checked out in subsequent years and has demonstrated good convergence. It agrees well also with the data of various authors for the various seismic zones of the earth. The divergence is within the limits of accuracy of the observations ($\pm$0.5); therefore it was also used when compiling the new map. The corresponding calculations with respect to the relation of M, K and J_0 facilitating the use of modern earthquake catalogs are presented in Chapters VI and VIII (see tables 7 and 12).

The preceding seismic regionalization map (Solonenko, V., et al,, 1960b; Solonenko, V., 1963a, 1968a), which is the basis for the state map (SNiP II-A. 12-69, Irkut Oblast, Buryat ASSR, Chita Oblast) was compiled on the seismostatistical (Southern part of Eastern Siberia) and predominantly tectonic and paleozeismogeological material. The instrumented data were very meager, for before 1952 there was only seismic station (Irkutsk), and then three, but all located in Southern Pribaykal'ye. Since 1961 the station network has been expanded significantly, and it provides for recording earthquakes with K = 7 for the entire rift zone, with the exception of a small section of the central part of Baykal from Lake Ol'khon to the Svyatoy Nos Peninsula (representative class K = 8). For the adjacent parts of the Siberian Platform and Transbaykal, earthquakes with K = 8 are representative; for Southeastern Transbaykal, earthquakes with K = 9. In addition, significant factual data have been obtained by the network of temporary seismic stations in the Udokan region (1962-1965), in Pribaykal'ye (1963-1965) and the Barguzin Basin (1972-1973).

At the same time broad seismogeological and special geophysical studies and a great variety of analytical seismological and geomorphological-geophysical operations were performed.

It is natural that for such a broad territory as Eastern Siberia where an area of about 1.5 million km^2 has been subjected to regionalization, it is impossible to collect the entire set of seismogeological, seismologic and geophysical data with the same degree of detail; therefore when estimating the seismicity of one territory or another, preference has been given to the method most "representative" for the given section.

Inasmuch as an earthquake is a physical-geological phenomenon, the regionalization naturally has been carried out first of all on a seismotectonic basis. However, in all phases of seismic regionalization seismologic and geophysical data were used:

1) When compiling the seismotectonic map, the seismological data were taken into account in order to discover the specific seismogeological relations in structural fields with nonsharply expressed boundaries between the morphostructures, for classification of the dislocations with a break in continuity and for solving a number of other problems;

2) When compiling the protential seismicity map (possible epicentral zones of maximum earthquakes): along with the seismostatistical and paleoseismogeological data maps of the seismic activity, maximal earthquakes and long-range forecasting of seismic activity were used. The probable regions of short-term "seismic calm" (see Chapter X) were also taken into account. When isolating the zones of increased center activity, the graphs of the recurrence rate of the earthquakes were considered;

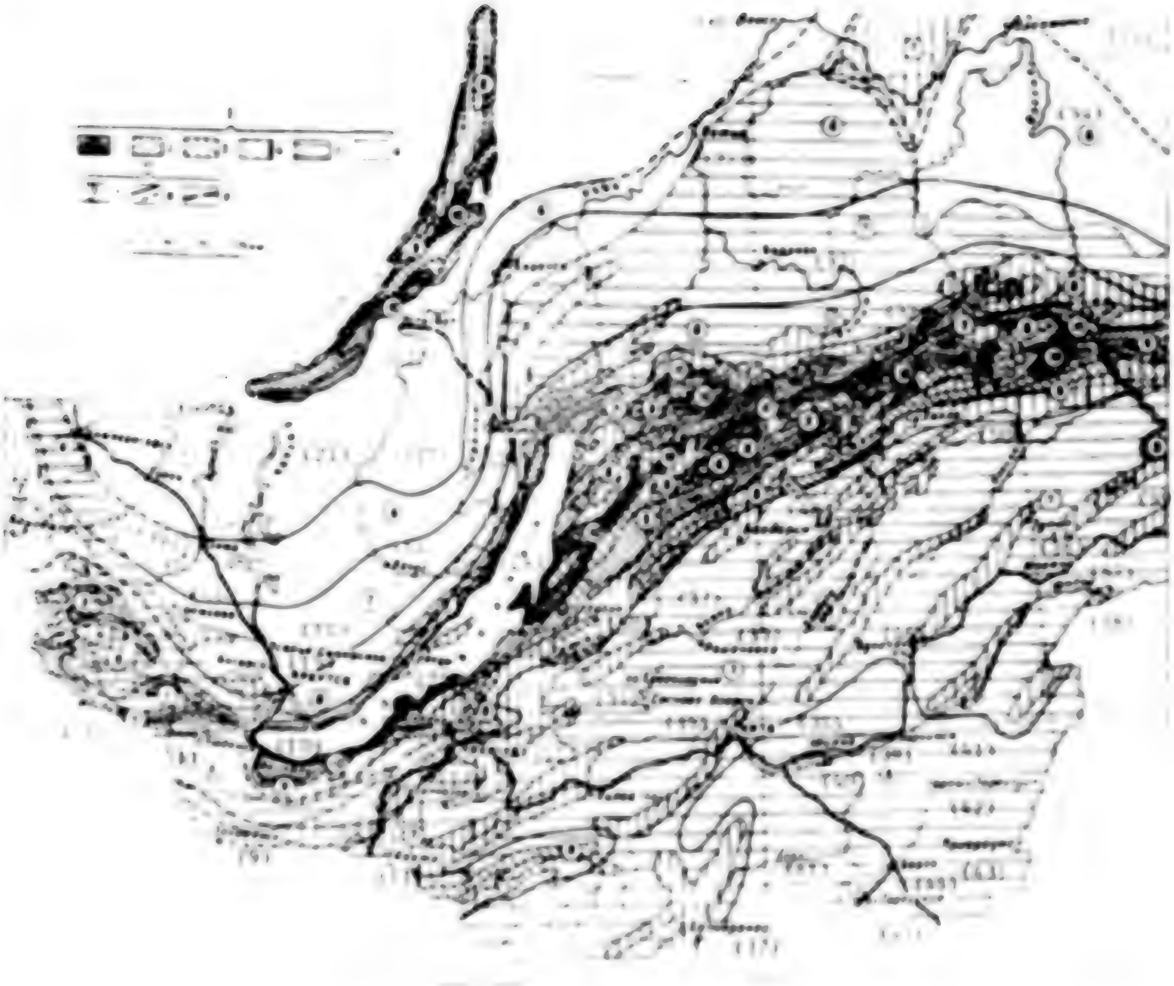
3) When calculating the averaged isoseisms, in addition to asismostatistics and the data on seismic dislocations, calculations of the damping of the oscillations were also used;

4) In the concluding phase of the regionalization, all of the isolated regions were checked and corrected with respect to all of the seismological and geophysical maps.

The basic difficulties of regionalization were encountered when estimating the seismic danger of a territory where there are no paleoseismodislocations. Wherever there are epicenters of strong historical and modern earthquakes, in these seismogenic morphostructural zones, there are no paleoseismodislocations. Wherever there are no paleoseismodislocations or there are fewer of them and they are unreliable, there are no seismologic data sufficient for seismic regionalization (Transbaykal). The difficulties also arise from the fact that the geological data in the absence of paleoseismodislocations do not up to the present time have a reliable quantitative expression. Nevertheless, for territories with seismological and paleoseismogeological material insufficient for regionalization it is necessary to use the radiants of the vertical tectonic movements. From what has been stated it is clear that our seismic regionalization map cannot be put in any definite category ("seismostatistical," "seismotectonic," "tectonophysical," "quantitative," "paleoseismogeological," and so on), and it is in the complete sense a map of complex seismic regionalization.

By the level of seismic activity in the regionalized territory three regions are clearly isolated (Figure 108): 1) the Siberian Platform--in practice an almost aseismic region with "transit" earthquakes from the Baykal seismic belts; 2) Transbaykal with moderate seismic activity and with "transit" earthquakes from the Baykal rift zone and Northern Mongolia; 3) the Baykal rift zone with maximum seismic activity.

Whereas for the last zone the paleoseismogeological data can serve as reliable indexes of the higher level of seismic potential, for the platform they are completely invalid, and for Transbaykal they have auxiliary value (the paleoseismodislocations are few and unreliable). The seismostatistical data for Transbaykal are also unreliable, for before the middle of the 20th century there are only spotty data on the earthquakes, and the seismic stations (two in all of this enormous territory) have been in operation for 3 to 5 years. It is natural that for moderate seismic activity there are insufficient data for compiling the activity and K_{max} maps. Accordingly, an effort has been made to determine the seismic potential of such regions by the quantitative method of M. V. Gzovskiy.



Fi ure 108. [See following page]

Figure 108. Map of the seismic regionalization of Eastern Siberia. Compiled by V. P. Solonenko, R. A. Kurushin, M. G. Dem'yanovich, S. V. Lastochkin, V. V. Nikolayev, S. D. Khil'ko, V. S. Khromovskikh, V. M. Kochetkov, V. M. Zhilkin, A. D. Abalakov. Edited by V. P. Solonenko.

[See preceding page for Figure 108]

The zones of possible occurrence of the earthquake centers or their magnitude (M) and the indication of the example intensity (I_0): 1 -- M>7 (force 10 or more); 2 -- M -- 6-1/2 to 7 (force 9), 3 -- M=5-1/2 to 6-1/2 (force 8-9), 4 -- M=4-3/4 to 5-1/2 (force 7-8), 5 -- M≤4-3/4 (force 7 and less than 6), 6 -- in practice aseismic regions. The seismic regions: 7 -- probable maximum strength of the earthquakes in force points by the MSK-64 scale; 8 -- boundaries of the regions with different force: a -- reliable, b -- proposed; 9 -- schematic of the BAM [Baykal-Amur railroad] route.

Key:

1 -- Nizhneangarsk; 2 -- Tulun; 3 -- Alygdzher; 4 -- Zita; 5 -- Cheremkhovo; 6 -- Orlik; 7 -- Mondy; 8 -- Slyudyanka; 9 -- Zakamensk; 10 -- Baykal'sk; 11 -- Kyakhta; 12 -- Gusinoozersk; 13 -- Ulan-Ude; 14 -- Selenginsk; 15 -- Irkutsk; 16 -- Kitoy; 17 -- Angarsk; 18 -- Usol'ye-Sibirskoye; 19 -- Kachug; 20 -- Yelantsy; 21 -- Angara; 22 -- Karenga; 23 -- Ust'-Kut; 24 -- Lena; 25 -- Kirensk; 26 -- Nizhneangarsk; 27 -- Vitim; 28 -- Kumora; 29 -- Lake Baykal; 30 -- Barguzin; 31 -- Turka; 32 -- Vitim; 33 -- Romanovka; 34 -- Lake Yeravninskaya; 35 -- Sosnovo-Ozersk; 36 -- Khilok; 37 -- Khapcheranga; 38 -- Chita; 39 -- Shilka; 40 -- Ingoda; 41 -- Nerinsk; 42 -- Gornyy Zerentuy; 43 -- Priargunsk; 44 -- Borzya; 45 -- Lake Toreiskiye; 46 -- Bukachacha; 47 -- Karenga; 48 -- Bogdarin; 49 -- Kalar; 50 -- Central Kalar; 51 --Chara; 52 -- Bodaybo; 53 -- Olekminsk; 54 -- Olekma; 55 -- Ust'-Nyukzha; 56 -- Tulik; 57 -- Mogocha; 58 -- Shilka 59 -- Nyukzha; 60 -- Lensk; 61 -- Onon; 62 -- Oka; 63 -- Iya.

The predominant latest and modern tectonic movements in Transbaykal constitute growth of the arch and arch-block uplifts (Florensov, 1960a; Khotina, 1966; Ufimtsev, 1971; and so on). Under these conditions a quantitative estimate of the vertical tectonic movements in connection with seismicity appeared possible. The method was tested in the example of Central Transbaykal (Lastochkin, 1972) where information was available about earthquakes to force 8 (M to 6), and paleoseismogeological studies were performed. The results of quantitative evaluation of the seismic potential gave satisfactory convergence with the actual data. This made it possible to extend the quantitative method of estimating the seismic potential to all of Transbaykal and to the edge part of the platform as a region with stable neotectonic regimen.

Gradients not exceeding $5 \cdot 10^{-10}$ years^{-1} which, according to the M. V. Gzovskiy classification (1963), correspond to in practice aseismic regions (to force 4-5) are characteristic of the platform. Of course, there can be exceptions here. For example, a force 7 earthquake (M = 5.2) occurred on the platform on 8 October 1974.

In Transbaykal the intraarea distribution of the gradients naturally, with a known proportion of provisionalness, permits the isolation of morphostructures with seismic potential to force 8-9 (gradients $6 \cdot 10^{-9}$ to $4 \cdot 10^{-9}$ years^{-1}), force 7-8 (gradients $4 \cdot 10^{-9}$ to $2 \cdot 10^{-9}$ years^{-1}) and less than force 7 (gradients $2 \cdot 10^{-9}$ to $1 \cdot 10^{-9}$ years^{-1}).

When isolating the seismic regions, primarily macroseismic data from the results of investigating strong earthquakes and the location of the epicentral zones of the preseismostatistical earthquakes with respect to paleoseismodislocations are used. These data have made it possible to establish the mean dimensions of the generalized isoseismal areas (see Table 19).

When compiling the table, as a result of the small number of data, especially on the strongest earthquakes (force 10-12), materials were used from investigating the strong earthquakes of Mongolia. Inasmuch as in Mongolia a different tectonic stress field prevails than in the Baykal Region [Pribaykal'ye], and during seismogenic movements of the earth's crust the shift component plays a significant role, the spread of the tremors has its specific peculiarities. Therefore the larger figures for the dimensions of the isoseismal areas along the structures pertain to the shift seismogenic structures. During regionalization of the highly seismic part of Eastern Siberia (the Baykal rift zone) with its normal fault, strike-slip normal fault and strike-slip thrust fault seismogenic structures, with predominance of the normal fault component, the most probable figures for the extent of the isoseismal areas along the structures are the minimum ones (Solonenko, V., 1964b, 1973a-c; SEISMOTECTONICS... 1968).

Table 19. Average dimensions (diameters, km) of the generalized isoseismal areas with respect to macroseismic effects

Intensity (force, MSK-64)	11-12		10		11		8	7	6
	along	across	along structures	across	along	across			
11-12	50-300	4*-25	200-400	30-110	220-450	100-225	120-510	300-1300	900-2000
10	--	--	50	4-6*	140	30	100-320	240-650	800-1000
11	--	--	2-3**	To 2***	To 500	To 15	50-130	110-200	210-380
8	--	--	--	--	14**	1-2***	15-40	60-160	120-350
7	--	--	--	--	--	--	--	15-30	50-90
6	--	--	--	--	--	--	--	--	15-20

* For one seismically active fault. In the epicenters of force 10 earthquakes with two parallel conjugate faults, 10-12 km; for block structures, 20-25 km.

** In the active fault zone the macroseismic effects are high by one force point.

*** On the active side (it depends on the width of the fault zone).

The isolation in the epicentral zones of the force 9 earthquakes of small force 10 sections (see Table 19) is connected with the fact that during the earthquakes with M $\geq$ 6.5, the seismogenic fractures, as a rule, reach the surface of the earth (see Chapter I) and significantly increase the macroseismic effect. The seismogenic joints and sharp oscillations of the walls of the faults with a residual amplitude to 0.8 meters and sometimes more (true amplitude approximately twice that; see Solonenko, V., 1968c; GOBI-ALTAY..., 1963, pp 326-328) unconditionally destroy any structure, even with force 9 antiseismic reinforcement.

The isolation of such sections is entirely logical: no one objects to increasing the force estimate by one as a result of unfavorable engineering-hydrogeological conditions, and what can be more unfavorable than a moving seismogenic fault zone? During general regionalization, the former cannot be reflected on the map (because of scaling conditions), at the same time as the seismogenic faults are a mandatory element of the center seismicity, seismotectonic, and seismic regionalization maps, and so on.

When investigating strong earthquakes in the Mongolian-Baykal seismic belt and according to the published data the following laws were established already 15 years ago (Solonenko, V., 1962b; SEISMOTECTONICS..., 1968, pp 146-149) confirmed by subsequent events both in the Soviet Union and in other seismic zones of the earth.

1. For linear seismogenerating structures the force 10-11 earthquake zone extends in a narrow strip along the seismogenic dislocations. The width of the zone is about 4 km on the active size (or sides) of the structure and 2-9 km, on the passive side. In the presence of feathering and accompanying fractures, it can increase to 10-12 km or more. For the block seismogenic structures the intensity of the tremor on the surface of the displaced structure is distributed nonuniformly--the difference for adjacent sections reaches several force points, but the variations with respect to area are not subject to advance calculation.

In the pleistoseism zones of force 10-11 earthquakes (Tsaganskoye, Muya, Bayan-Tsaganskoye, Mogodskoye, and so on) the established amplitude of the vertical and horizontal displacements reaches 7-8 meters, the amplitude of the surface waves in loose ground is up to 4-5 meters with a length on the order of 15-20 meters. In the loose ground the width of the gaping trench-joints is usual up to 4-6 meters, frequently to 10 meters, and in individual cases to 19 meters (ACTIVE TECTONICS..., 1966, pp 151-152). In the rocky ground joints are formed with gaping to 4-5 meters and obviously sometimes more.

The apparent opening of the faults on the surface of the earth along the strike is observed over an extent of up to 30 km (the Muya earthquake), and with predominance of the shift component, to 45 km (the Mogodskoye earthquake on 5 January 1967, M = 7 3/4). During the Muya earthquake the movements in the fault zone were observed to 90 km from the epicenter to the east (in the direction of the shift of the ridge) and to 50-55 km in the opposite direction.

The creation of economically and technically expedient antiseismic structures for force 10 zones is impossible; therefore they must be categorically closed for construction, with the exception of unavoidable communications which must cross such zones by the shortest path.

2. The force 9 regions with respect to seismic danger are nonuniform. In the seismogenic fault zone actually the force of the earthquakes exceeds the resistance of the structures with any earthquake-proofing construction. These movements are observed along the strike of the fault up to 50 km, and sometimes more. Therefore in the force 9 regions along the seismogenic faults at a distance of up to 2 km from them the erection of capital structures (with the exception of unavoidable communications) is inadmissible. On the seismic regionalization map, such sections are shown as possible center zones with $M = 6\frac{1}{2}$ to 7.

3. For the force 8 earthquakes in the epicentral segment of the seismogenic structure there are sharp, but as a rule, reversible oscillations of the walls of the faults and the macroseismic effects reach force 9 (on the average to 14 km along the fault and 1-2 km across it). Therefore it is necessary to avoid capital construction in such zones.

4. In the areas with thick (300-400 meters or more) series of nonmetamorphic sedimentary rock, the earthquake intensity decreases sharply and irregularly. Therefore in the internal parts of the basin in the absence of highly active seismogenic structures in their basement, the initial normative force of the earthquake can be low by one force point.

In order to outline the areas of the "transit" tremors in the direction of the seismogenic structures, it does not appear possible to use the standardized procedure. For example, by the calculated data for the circular isoseisms and by the average sizes of the isoseismal areas with respect to macroseismic effects (see Table 19) on the Siberian Platform the area of the force 6 region by comparison with the 1962 map (Solonenko, V., 1963a) should be expanded 200-250 km to the northwest, which contradicts the available macroseismic data. Therefore primarily seismostatistical data were used, and in case of a deficiency or in the absence of this data, the average data (see Table 19) considering the seismic vulnerability maps and also the specifics of the spread of the tremors over the summary isoseismal map.

When determining the boundaries of specific seismic regions, definite difficulties are encountered. The regions with possible force 10 earthquakes or higher and the sections of the force 9 regions with increased seismic danger require especially careful analysis of the seismogeological, seismologic and geophysical data. They, as has already been stated, must be first of all forbidden for capital construction (with the exception of communications) and, secondly, they must be the starting points for determining the boundaries of the "transit" tremor regions, including the platform sections where no local strong earthquakes occur. The problem is somewhat facilitated by the fact that these regions are within the boundaries of the Baykal rift system (with the exception of the near-rift zones of the Oka and Kitoy faults in Eastern Sayan).

During general regionalization, the concept of constantcy of the maximum earthquake energy over the entire extent of the seismotectonic fractures is used. For the Baykal rift, we have long refrained from using this rule (Solonenko, V., 1963a). In the overwhelming majori ·, the faults have more ancient occurrence, and the riftogenic processes causing high seismicity are Cenozoic. If a fault goes beyond the boundaries of the rift zone, the seismic acti ity decreases sharply (for the Obruchev fault system, from force 10-12 to force 5-6). Under these conditions, the question naturally arises of the limits of the force 10 region in the flank zones with potential seismic activity of force 10 or higher (see Figure 108). If we consider, as usual, that at any point of the section with potential seismic activity of force 10 there can be an epicenter of the corresponding force estimate, then the boundary of the force 10 region must be considered along the strike of the structure at least 25 km or more, and the force 10 region, 45 km (see Table 19). This lengthening of the high-force regions from our point of view is valid only in the case where the seismologic data indicate high activity of the fault zone beyond the proposed boundary of the rift system. In the opposite case the provisional epicenter of the future earthquake is taken in the center of the section of the seismically active zone which can insure a force 10 earthquake, that is, 25 km from the end of the structure. In this case the distal boundaries of the regions of potential seismicity and seismic regions (see Figure 108) of different intensity coincide.

On isolation of high-force regions, the probable recurrence rate of the strongest earthquakes is taken into account also. The earthquakes of force 11-12 were not considered, for their probability is very small. The traces of such earthquakes have been established only in three areas of the rift zone (Southern Pribaykal'ye, the western shore of Central Baykal and the Udokan Ridge), with intervals between their epicenters of 350 and 750 km where such earthquakes have never occurred at least during the last thousands of years. The possible force 10 earthquakes in isolated seismogenic structures, the potential seismicity of which according to geological and paleoseismogeological data will reach force 10 were also not taken into account, but the recurrence rate of such earthquakes is low (no more frequently than once in a thousand years according to the paleoseismogeological data and less than once in ten thousand years by the seismic vulnerability map), and by the seismological data, the activity and K_{max} are low. These regions belong to force 9.

Description of Seismic Regions

The basis for isolation of the regions, especially of high seismicity (force 9, 10 and higher) is the paleoseismogeological, seismotectonic and seismostatistical data. They determine the initial ("background") seismicity for

the average ground conditions[1]. Along with this, seismological and geophysical materials are used (the time-space distribution of the earthquakes, the seismic activity of the region of specific seismogenic structure and the probable maximum earthquake center with respect to K_{max}, the long-range forecasting of the seismic activity, the "preparation" zones, and so on).

The increase or reduction in the force estimate as a result of the engineering-geological, geocryological, geomorphological and other purely surface factors which are taken into account only during detailed seismic regionalization and microregionalization are not reflected on the seismic regionalization map.

The boundaries of the seismic regions of higher forces on the whole do not correspond to the boundaries of the center zones of highest activity taking into account the entire set of geological-geophysical data. However, there are no exact boundaries of such zones in nature, in connection with which the boundaries of the seismic regions can be drawn only within the limits of the defined fiducial intervals of values of different intensity and activity of the observed processes.

The boundaries of the high-seismic (force 9 and 10) regions have been drawn the most definitely. Their isolation is clearly controlled by the neotectonic structures with highest seismic potential, the paleoseismogenic structures and modern seismic dislocations and also the entire set of seismologic data. The regions of moderate and low seismicity (force 8, 7 and 6) which are isolated predominantly by the seismostatistical, seismologic and averaged macroseismic data (see Table 10) and also by the type of latest structures, degree of intensity and contrast of the neotectonic movements are less reliably outlined.

1. The regions with earthquake intensity of force 10 or more extend spatially to the Baykal rift zone. Genetically they are closely connected with the marginal parts of the large rift structures, being located along the zones of activated ("seismogenerating") faults. Among them the clearest examples are Tunkinskaya, Obruchev, Kodar, Udokan, the Stanovoy fault system, the Cherskiy fault and other seismically active lineaments. These include the short dislocations with a break in continuity activated in the anthropogene, developed in the regions of highly seismic regional interbasin commissures where, as a rule, they control the development of the small rift structures of the type of type of the generating and embryonic basins.

In the majority cases the isolation of the epicentral regions of maximum seismicity is substantiated by the paleoseismotectonic structures, the formation of which occurred during earthquakes with M on the order of 7 or more.

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[1] By the average ground we mean the natural sand-loam series with deep occurrence of ground water of more than 8 meters (from the level to surface).

In addition to the structural-tectonic and the seismogeological criteria, the isolation of such zones is substantiated by an increased concentration of the epicenters of moderate and weak earthquakes, which is reflected on the seismic activity map (the values of A_{10} for them usually do not drop below 0.2).

The highly seismic epicentral regions extent in narrow (from 1-2 to 8-10 km) strips along the riftogenic faults. Here the fault zones with simple structure, with the clearest contrast of the neotectonic movements (for example, Tunkinskaya, Obruchev, Barguzin, Kodar, and so on) give rise to still clearer and straighter boundaries of the force 10 seismic regions. In the case of complex structure of such zones (echelon structure, broad development of accompanying and feathering dislocations, variations of the active faults, sharp block diffrentiation in the marginal and axial parts of the uplifts bordering the rifts, the system of generating basins, and so on) the force 10 seismic regions are expanding and have complex configuration. This is especially characteristic for the rift sections of the arch-block uplifts (Khamar-Daban, Udokan) and the large interbasin mountain commissures (Upper Angara-Muya, Muya-Chara). For regionalization of the highly seismic zones it is assumed that the single seismotectonic lineament is seismically dangerous to an equal degree along its entire extent. However, as has already been noted at the beginning of the chapter, the large, extended zones of "seismogenerating" faults are divided into sections with different level of seismicity. First of all, this pertains to the faults which go beyond the limits of the tectonic stress field of the Baykal rift zone both on its flanks and on the periphery. Accordingly, significant sections of the Tunkinskaya, Eastern Saya, Obruchev, Barguzino-Muya, and Stanovoy systems of activated faults are included in the force 9 seismic regions, and against this background they are considered as zones of increased seismic danger. For such sections, the absence of explicit signs of seismogenic rejuvenation and a lowered level of modern seismic activity are usually characteristic (see Chapter XI).

In addition to the neotectonic and seismogeological factors, the isolation of the force 10 regions is confirmed by the seismostatistical data--the epicenters of strong (force 9-10) earthquakes and also increased concentration of the epicenters of moderate and weak shocks within their boundaries (see Figure 73-75), which is reflected on the seismic activity maps (see Figures 76-78) and maximum earthquakes (see Figure 89). The values of A_{10} for such regions usually do not drop below 0.2. However, in the Baykal-Stanovoy seismically active zone there are a number of force 10 regions which on the seismic activity maps and the maps of maximum possible earthquakes correspond to low values of A_{10} (≤ 0.05, and $K_{max} < 14$). Examples: the Muya Basin, the Northern Baykal part of the Obruchev faults, the Upper Angara, Parama and China-Vakatskiy (eastern part) fault zones in the Stanovoy Highland. The inclusion of such sections in the force 10 regions, in spite of the noncorrespondence to the seismological data, is substantiated primarily by their seismotectonic position (all of them control the development of rift structures and embryonic basins) and coordination of the paleoseismogenic structures occuring during earthquakes with an intensity of no less than force 10 with them.

For the Obruchev fault zone these are the following structures: Southern Rita, Shartlay, Srednekedrovaya [Central Kedrovaya], Khibelenskaya, Solontsovaya; for the eastern part of the Upper Angara fault--the Ogney structure and the generating Churo graben; for the vicinity of the Muya Basin--Taksin and Parama structures, and for the eastern section of the China-Vakatskiy fault--the Medved' structure (see Chapter VII). Many of the enumerated sections with respect to macroseismic information and instrument data are confirmed by the epicenters of strong (on the order of force 8) earthquakes. Thus, for example, on 6 August 1931, an earthquake occurred in the vicinity of the northwest shore of Lake Baykal with a proposed intensity of more than force 8; in the vicinity of the northeastern border of the Upper Angara Basin instruments recorded two earthquakes with an intensity of up to force 7 (11 March 1936 and 17 September 1957); in the same region on 18 August 1902 an earthquake was felt, the force of which at the observation point reached force 8 (see Chapter VII).

It is also proposed that at least part of such zones (for example, east of the end of the China-Vakatskiy and the Upper Angara faults) corresponds to the regions of "preparation" of strong earthquakes (see Chapter X).

When isolating the force 10 regions on the map, the possibility of the occurrence of earthquakes also with greater intensity is suspected, which is indicated, for example, by certain paleoseismogenic phenomena within the boundaries of the Baykal rift (the Shartlay, Southern Rita structures) and the Stanovoy Highland (China-Vakatskiy structure). However, the recurrence rate of such seismic disasters on the whole for the territory of the Baykal-Stanovoy seismic zone is low (according to the paleoseismogeological data, no more frequently than once in 500-600 years). In practice they are excluded from the regionalization and must be considered only when constructing especially important long-range projects.

The regions with earthquake intensity of force 10 or more occupy an area of 33,800 km^2, which is almost twice the area of the force 10 regions isolated on the seismic regionalization map of Eastern Siberia of 1962 (Solonenko, V., 1963a). The area was increased as a result of inclusion of the water part of Lake Baykal in the regionalization (about 8,000 km^2) and partially as a result of isolation of new force 10 regions in the rift zone of the Stanovoy Highland (about 7,000 km^2) discovered during complex seismogeological studies in the last decade (ACTIVE TECTONICS..., 1966; SEISMOTECTONICS..., 1968, 1975a,b). The unavoieability of this increase was proposed also earlier (Solonenko, V., 1963a). The regions with maximum intensity of the possible earthquakes have also been isolated here along the riftogenic fault zones controlling the northeastern part of the Upper Angara Basin, the northern and western sides of the Muya Basin and the system of small (embryonic) basins of the Baykal type within the boundaries of the Upper Angara-Muya, the Barguzino-Muya and the Muya-Chara interbasin mountain commissures. The force 10 regions along the Tunkinskiy and the Barguzin fault zones and northeast of the Svyatoy Nos Peninsula have been increased somewhat. In the latter case the highly seismic region encompasses the Bol'sherechenskaya

and the Sosnovskaya satellite basins and the zones of the latest faults bounding them (SEISMOTECTONICS..., 1968; Abalakov, 1973) located on the continuation of the seismically active Central Baykal interbasin commissure. Two new small force 10 regions have been isolated on the northeastern flank of the Baykal rift zone, on the left bank of the middle course of the Olekma River (Olekma-Chara interfluve). They outlined the seismogenic structures of the epicentral regions of three strong earthquakes--Olekma and Nyukzha 1958 and Tas-Yuryakhskoye 1967 (ACTIVE TECTONICS..., 1966, SEISMOTECTONICS..., 1975a).

The force 10 seismic regions must be forbidden for capital construction. It is necessary to consider the fact that in the majority of cases these regions, as a rule, are characterized by extremely unfavorable or unsuitable engineering-geological and geomorphological conditions for construction. Only special state interests or special economic requirements can justify the erection of certain engineering structures in these areas. It is true that in individual cases, especially where significant expansions of the force-10 regions are indicated on the described map (Southern Baykal, the Muya-Chara zone), on detailed investigation and microregionalization, it is possible to isolate areas with reduced seismic danger. The scale does not permit indication of such small sections on the map, but it is necessary to consider that the possibility exists.

2. The regions with earthquake intensity of force 9 occupy the largest areas in the Baykal-Stanovoy seismic zone, primarily along the system of Baykal rifts and on its flanks. Essentially all of the morphostructural elements of the Baykal rift zone (primarily the rift basin) are characterized by force 10 potential seismicity. In the regions of the uplifts directly bounding the rift basins, these areas include the complexly differentiated central parts of the side and the arch-block morphostructures removed from the zones of maximum (force 10) seismicity.

The outlines of the force 9 seismic regions are connected both with local center zones and with the extent and configuration of the force 10 regions from which the force 9 surface effects extent (the "transit" tremors). According to Table 10, during an earthquake with an intensity at the center of $M \geq 7$ this effect can extend to a distance of up to 30 km across the strike and 140 km along the seismically active structures. Thus, in the force 9 seismic regions bordering the broad belt of the activated fault zone with established maximum (force 10 and higher) seismic danger, obviously the "transit" oscillations play a significant role. Moreover, centers of force 9 earthquakes are possible here according to seismotectonic conditions.

In the regions of mature rift basins, the force 9 zones include longitudinal rift forming faults or the set of echelons of such faults (without apparent traces of seismogenic rejuvenation) controlling the maximum plunged sections of the basement. In the formation of the articulation zones of these basins with the mountain borders a significant role is played by the bending deformations, and the mean velocities, in spite of the maximum scale of the

neotectonic movements probably is somewhat less than in the small riftogenic morphostructures. In the mature basins, in addition, the zones of force 9 seismic danger include the intrabasin commissures and lateral projections that are manifested on the surface characterizing the sharp differentiation and increased contrast of the movements of the individual blocks of the basement of higher orders.

The large regional interbasin commissures are in practice completely associated with the zones with possible occurrence of force 9 earthquakes. Such zones here include the small rift basins, the bottoms of which, as a rule, are differentiated with deformation of local intrabasin and interbasin commissures, and the sides are frequently complicated by young longitudinal and transverse faults. Usually the embryonic basins of this type are separated by commissures into a series of depressions as a result of which, inside them the blocks with different signs and rates of latest movements are in contact. Within the limits of these negative morphostructures it is possible to expect the occurrence of residual seismotectonic deformations connected with the local force 9 shocks and ones excited by maximal earthquakes, the hypocenters of which are within the zones of the main rift forming faults. The examples of the Muya (1957) and the Mondy (1950) earthquakes indicate this quite obviously.

The regions of probably force 9 earthquakes M = 6 1/2-7, within the limits of regional commissures also include the sharply differentiated parts of the block morphostructures usually located between the zones of increased seismic danger. Here we also have the parts of the faults having maximum degree of seismic danger with respect to geological and seismic data (M >), but going beyond the limits of the morphostructures which cause this danger. (For example, the Muyakan fault, the northeastern parts of the vicinities of the Upper Muya, the Uchargasskiy, the western parts of the Southern Muya, the Konda-Eymnakhskiy and many other faults in the regional commissure areas).

Thus, in the force 9 regions the seismic danger depends on the manifestation of both local earthquake centers with M = 6 1/2-7 and the surface effects of the "transit" tremor from the direction of the seismogenic structures of high potential (M > 7). Here the force 9 regions are constricted in the case of the simply outlined force 10 zones (for example, Tunkinskaya, Eastern Sayan, Baraguzin, Obruchev, Upper Angara) and they expand significantly in the case of complex configuration of them (Southern Baykal, Muya-Chara regions).

It is necessary to note that in the investigated territory of Eastern Siberia, significant sections of force 9 regions with respect to area are not always confirmed by strong earthquakes and high level of modern seismic activity. However, with respect to the neotectonic situation, the degrees of differentiation, contrast and amplitude of the latest movements, intensive rearrangement and development of the neotectonic structures they are analogs of the areas with the established force 9 seismic potential. For example, the

flank parts of the Baykal rift zone (Eastern Sayan and the Stanovoy uplift) and certain morphostructures of the transitional type from the direction of the Transbaykal block-wave zone (Khamar-Daban, Ikat, Udokan-Kalar, the fault-block uplifts) are under such seismogeological conditions. Nearer to the marginal part of the Siberian Platform the force 9 regions are constricted, which is connected with a sharp reduction in the seismic potential of the uplifts bordering the rift zone to force 8 and even 7 (Primorskiy, Upper Angara, Northern Muya, Delyun-Uranskiy ridges) and the appearance of predominantly (transit) tremors with an intensity to force 9 from the center zones of the force 10 earthquakes.

In seismotectonic respects the force 9 regions, in contrast to the regions of maximum seismicity, encompass not only the rift zone itself, but they also go beyond its limits. This is caused by the peculiarities of the seismogeological relations and nonuniformity of the seismic manifestations within the limits of the transition morphostructures. This nonuniformity is felt primarily in the fact that the force 9 regions are outlined in the cases of: a) combination of local force 9 centers and "transit" force 9 tremors from the maximum seismicity zones; b) superposition of force 9 "transit" tremor on the structures within the limits of which the earthquakes with M to 6 1/2 are possible; c) local earthquake centers with intensity of force 9 ($M \geq 6$ 1/2).

In connection with the fact that the paleoseismogeological data are explicitly inadequate (on the basis of the fast denudation destruction of the traces of the residual deformations in the force 9 pleistoseism zones), the analysis of the seismological and geophysical materials has great significance when isolating the force 9 regions. Above all, these regions are located within the limits of the regions characterized by increased values of the seismic activity ($A_{10} \geq 0.1$). The same values characterize the epicentral regions of historically known force 9 earthquakes (see Chapter VII). The same thing can also be said about the K_{max} map on which the force 9 seismic regions as a whole correspond to the areas where the occurrence of maximum earthquakes with $K \geq 15$ is assumed. The map of the long range forecast of the seismic activity in general features also confirms the boundaries of the force 9 regions.

However, a direct comparison of the high force regions isolated with respect to the seismogeological and morphostructural criteria with the maps of the seismic activity and maximum earthquakes indicates that in a number of cases (Olekma-Chara interfluve, the northern border of the rift zone of the Stanovoy Highland, the southern part of the Northern Baykal Highland, Eastern Sayan, Khamar-Daban) there are noncorrespondences: force 9 seismic regions, for example, are characterized by low values of A_{10} and K_{max}. The explanation for this (in addition to the existence of the "zones of calm" see Chapter X) can be found in that the adopted functional relation $K_{max} = K_{max}(A)$ does not take into account all aspects of the interrelation of the strong and weak earthquakes. Thus, for the vicinity of the Ikat ridge with its high values of A_{10} the absence of strong shocks (seismostatistics since the

beginning of the 19th century) and paleoseismodislocations is characteristic, and within the limits of Southern Baykal and the Tunkinskaya zone for comparatively low values of the seismic activity, epicenters of strong earthquakes and paleoseismodislocations are known.

The seismogeological and seismological studies performed in the last decade on the territory of Eastern Siberia permitted significant more precise definition and more reliable substantiation of the boundaries of the force 9 seismic regions. Here their areas were significantly reduced on the northeastern flank of the Baykal rift zone and from the direction of the marginal part of the Siberian Platform. The total area of the force 9 regions in the investigated territory by comparison with the seismic regionalization map of 1962 was reduced by 62,500 km^2.

The small increase in area of the force 9 regions took place in Western Transbaykal within the limits of the morphostructures of the transitional type (Ikat and Tsipa-Bauntovskiy sections), primarily as a result of the force 10 zones (SEISMOTECTONICS..., 1968). For example, the vicinity of the Ikat ridge has, according to the instrument data, a very high level of seismic activity (A_{10} = 0.5-1), and the calculations of the seismic vulnerability permit us to expect earthquakes in it with an intensity of more than force 9 with a recurrence rate of 2,000 to 5,000 years. However, the absence of clearly expressed paleoseismogenic structures does not provide grounds for isolation of a force 10 region here. In addition, this area is located on the periphery of the highly seismic rift zone and partially goes beyond its limits. The nonuniformity of the structure of the earth's crust established in the Ikat region, and the "layer by layer" stress distribution in cross section and different earthquakes with respect to center mechanism established in the Ikat region (see Chapter IV) obviously create favorable prerequisites for constant relief of the stresses by numerous, but weak (K_{max} = = 12) earthquakes. However, con connection with the seismotectonic peculiarities of the transition morphostructures with broad development of the faults active in the Cenozoic (Ulan-Burka, Garga, Ikat, and so on) and the formation of the embryonic basins in the axial part of the uplift, the isolation of the force 9 region here appears to be substantiated.

On the continuation of the Ikat zone to the northeast there are transitional morphostructures of the Bauntovskiy Region also considered in force 9. This includes the Tsipa-Bauntovskiy system of subrift depressions, Kadalinskaya, Bambubukoyskaya, the Tilishminskaya embryonic basins and the uplifts directly bordering them. The seismic potential of these morphostructural elements is high and can reach force 9-10 which is indicated primarily by the paleoseismogenic Khapton and Tilishminskaya structures detected here with an age on the order of the first thousand years (see Chapter VII). The seismic activity of the Bauntovskiy territory is high ($0.1 \leq A_{10} \leq 0.35$), and earthquakes are possible with K_{max} to 16. However, the recurrence rate of the force 10 earthquakes is sparse here (according to the seismologic datat, every 20,000 to 50,000 years). Thus, with respect to the set of seismogeological data the system of Tsipa-Bauntovskiy and Tilishminskiy transitional structures is distinguished by reduced (by comparison with the rift zone) seismic potential and belongs as a whole to the regions with force 9 seismic danger.

Here the Tilishminskiy fault zone controlling the development of the embryonic basin and bearing traces of force 10 earthquakes remains a region of increased seismicity.

The force 9 regions both with respect to structural-tectonic and engineering-seismogeocryological characteristics, and with respect to seismic danger, are nonuniform. With detailed investigations this permits isolation (especially in the large rift basins with a thickness of the loose deposits of more than 300 to 400 meters) of the areas, the initial normative seismicity of which can be low by 1 force point. Nevertheless, it is necessary again to emphasize that under the conditions of Eastern Siberia in the force 9 seismic regions, especially on the island permafrost, the choice of sections for large-scale construction requires preliminary detailed engineering-geological, seismogeocryological and seismic studies, and the zones of increased seismic danger (seismically active faults) in general must be excluded for capital construction (naturally, with the exception of communications).

3. The areas with earthquake intensity of force 8 occupy the smallest areas in the mountain belt of Eastern Siberia, encompassing the marginal parts of the Sayan-Baykal-Stanovoy arch. In Transbaykal they include the vicinity of the Chikoy Basin which previously was classified as force 7 increased seismic danger (Solonenko, V., 1963a)[2].

The isolation of the force 8 seismic regions is caused both by the spread of the "transit" tremors from the highly seismic regions and by local centers with intensity to force 8. The greater part of them are located at significant distance from the highly active rift zone.

The boundaries of the force 8 regions are substantiated first of all by reduced seismic potential of the neotectonic structures on the limbs of the Sayan'-Baykal-Stanovoy arch and, secondly, the width of the zones encompassed by the "transit" tremors from the direction of the highly seismic (force 9 and 10) regions (see Table 20) [sic--perhaps they mean Table 19--Translator]. In addition, the small force 8 regions with respect to area are isolated within the limits of the rift zone itself. This is primarily the internal, deeply (more than 300-400 meters) plunged parts of the large rift basins with weak differentiation of the basement removed from the seismic active borders (for example, the Northern Baykal Basin). The scale of the map does not permit depiction of such sections in other rift structures with thick series of loose deposits. However, it is necessary to consider that in the Tunkinskaya, the Barguzin, the Upper Angara, the Muya and the Chara Basins it appears possible to isolate small force 8 areas. This pertains also to the central, weakly differentiated parts of certain rift uplifts (for example, Barguzin, Southern Muya, Udokan, Kalar and Kodar Ridges).

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[2] In the SNiP-IIA, 12-69, by recommendation of the editorial commission of the Earth Physics Institute of the USSR Academy of Sciences it was included in the force 6 regions although this contradicted the factual data (Solonenko, V., 1968a, page 367).

On the whole, the force 8 regions, with respect to their structural-geological peculiarities and nature of seismic manifestations, are still more nonuniform than force 9. Among them the following are isolated:

1. The moderately active areas ($A_{10} = 0.02-0.1$, $K_{max} \leq 14$), where both local force 8 earthquakes and the "transit" tremors from the center zones of highly seismic (force 9 and 10) regions occur. In the rift belt, as has already been noted, these are the central parts of the large basins and the axial sections of the arch-block and block uplifts removed from the seismically active faults. These include also the flank morphostructures of the Baykal rift zone within the boundaries of the arch-block uplift of Eastern Sayan and Stanovik.

2. The weakly active ($A_{10} = 0.01-0.05$; $K_{max} = 12-13$) regions of predominantly "transit" tremors with low recurrence rate of local shocks with intensity to force 8. These are the marginal, weakly differentiated parts of primarily the arch uplifts and depression lowlands in the transitional region to the Transbaykal block-wave zone.

3. The in practice "centerless" areas with extremely low values of the modern seismic activity ($A_{10} \leq 0.01$), where only the "transit" tremors are exhibited. These are predominantly the marginal (shield) uplifts and to a lesser degree, the foothills troughs of the activated part of the Siberian Platform.

4. The moderately active region of the Chikoy Basin in Southwestern Transbaykal (see below).

The macroseismic study of strong earthquakes (force 9, 10 and higher) in the territory of the Mongolian-Baykal seismic belt and the seismogeological analysis of the residual deformations indicate (see Table 20 [sic]) that the force 8 surface effects extend from the epicenter of the force 9 earthquake (with a depth of center of 15-20 km) to a distance of up to 130 km, and force 10, to 160 km. Accordingly, an extraordinarily nonuniform intensity distribution on the earth's crust is noted (especially in the presence of complex engineering-geological, geomorphological and geocryological conditions). Therefore the "mechanical" outlining of the force 8 regions by the magnitude of the established maximum radii of the corresponding isoseisms can lead to significant unjustified expansion of the area of the regions.

The "transit" tremors of the force 9 and 10 center zones of highly seismic regions are in the final analysis defining when drawing the boundaries of the force 8 regions. Here, in all of the known cases the force 8 macroseismic effects (average) of the strongest earthquakes of the Baykal-Stanovoy seismic zone have not spread more than 160 km from their epicenters, and this boundary was taken as initial for the initial external boundary of the force 8 region. Then it was corrected depending on the seismotectonic situation, the nature of the epicentral fields, the isolines of seismic activity, K_{max}, and so on. Here a check was made with respect to macroseismic effects (also average) from the force 9 center zones. However, for definite quantitative estimates of these regions (especially in the marginal zones of the Sayan-Baykal-Stanovoy arch) there are still insufficient instrument and

seismogeological data, and it is necessary to use the materials with respect to other seismically active regions (Mongolia, Central Asia, California, and so on).

On withdrawing from the axial Baykal-Stanovoy seismic zone, two force 8 regions are isolated in which the centers of the local earthquakes with an intensity to force 8 ($K_{max} \leq 15$) are possible. In the investigated territory of Eastern Siberia, both of these regions are represented only by their marginal parts.

One of them--the northwestern flank of the extended Tukuringra-Dzhagdinskaya seismically active zone--encompasses part of the Chernysheva and Tukuringra ridges extending to the Upper Zeysk Basin. This region on the existing seismic regionalization map (SNiP-IIA 12-69) belongs to force 5-6. However, the seismogeological and the instrument studies performed here in 1970-1971 and in 1974-1975 in connection with planning the BAM [Baykal-Amur Railroad] route and building the Zeysk Hydroelectric Power Plant [SEISMOTECTONICS..., 1975b) have made it possible to reexamine the estimate of the seismic conditions of this territory.

The force 8 potential seismicity here is determined by the modern tectonic activity of the Tukuringra arch-block uplift and the systems of latest faults bounding it (Gilyuyskiy, Tukuringra, Southern Tukuringra, and so on), partially entering into the Mongolian-Okhotsk deep fault zone. These structures are connected with quite numerous epicenters of earthquakes with K = 9-14. In recent years force 6-7 shocks were recorded here, and on 2 November 1973, the Zeysk earthquake occurred with M = 5.6; K = 14, I_0 = force 8 (Semenov, Avdeyev, 1975). It confirmed the correctness of the isolation of the force 8 region along the Tukuringra zone. According to the preliminary seismogeological materials, in 1967 V. N. Solonenko already forecasted high seismic activity of this territory.

In connection with what has been discussed, the force 5-6 estimate of potential seismicity of the Zeysk Region finding reflection in the SNiP II-A. 12-69 appears to be extremely unsubstantiated, which, beginning in 1967, was made known by the design organizations (Lengidroproyekt, Gidroproyekt).

In Southwestern Transbaykal, the Chikoy Basin is considered to be force 8. According to the seismic data in it moderate seismic activity is noted (A_{10} = 0.01-0.02; $K_{max} \leq 13$), that is, the expected maximum earthquake intensity here can reach force 7.

However, the Chikoy Basin is part of the broad Khentey-Daurskaya seismically active zone which reaches into Northern Mongolia. The western segment of this extended zone in the territory of Mongolia exhibited itself in 1905 with the strongest earthquakes (M = 8.4 and 8.7; J_0 = force 11 and 12).

For the vicinity of the Chikoy Basin, according to seismostatistics, a force 8 ($M = 6$) earthquake was known in 1934 (Solonenko, V., 1968a, page 367); in addition, during the seismogeological studies (Lastochkin, 1972) the residual deformations of the force 9 earthquakes were established here (the Yadrikhinskaya and the Kuyuktuyskaya structures). The possibility of the occurrence of the centers of force 8 earthquakes in this area is also indicated by the highest magnitude of the velocity gradients of the vertical neotectonic movements for the territory of Transbaykal-- $|\text{grad } V|_m \approx (0.4\text{-}0.6) \cdot 10^{-8}$ year^{-1}.

All of this forces us to classify the Chikoy Basin as force 8. Its boundaries are drawn considering the nature of the damping of the macroseismic effects in the example of the earthquake of 1934 (Popov, 1939) and using data on the averaged isoseisms (see Table 29 [sic]).

The regions with earthquake intensity of force 7 encompass large areas with comparatively weak differentiation, contrast and intensity of the latest tectonic movements. On the one hand these regions include the weakly active ($A_{10} < 0.01$; $K_{max} < 12$) marginal uplifts of the Aldan Shield, the Northern Baykal and the Patomskiy Highlands and the potentially aseismic marginal troughs and uplifts of the Irkut amphitheater, and on the other hand, the greater part of the Transbaykal block-wave zone (A_{10} - 0.01-0.05; K_{max} = 12-13) and the section of the Nyukzha-Gilyuyskiy depression between the Stanovoy Uplift and the Tukuringra Ridge.

In the direction of the Siberian Platform, the centers of local earthquakes (with K within the limits to 10) are extremely rare with the exception of the activated part of the Aldan Shield were in the vicinity of the Chul'man depression and the uplifts framing it on the north, increased seismic activity is noted (A_{10} to 0.05), and it is possible to expect an earthquake with K_{max} = 13). The seismic dangers of these territories is determined basically by the "transit" tremors from the center zones of the force 8-10 regions. In the Irkut amphitheater, the local force 7-6 centers are in practice excluded. At the same time the macroseismic data with respect to strong earthquakes from the highly seismic zones give rise to the isolation of the force 7 region over a significant territory of this stable and rigid block of the earth's crust, including primarily the Pristanovoy and Predbaykal'skiy troughs. On the whole the boundary of the force 7 region on the Siberian Platform side, by comparison with the preceding map, was left unchanged with the exception of the small sections in the southern part of the Aldan Shield and in the Baykal-Patomskiy Highland where it is augmented as a result of the force 8 region.

The new force 7 seismic region is isolated in the southern part of Yakutia within the limits of the marginal structures of the Siberian Platform, the seismicity and the latest tectonics of which have not been investigated, and therefore they were considered aseismic (with respect to their platform situation). However, on 8 October 1974, a force 7 earthquake occurred here ($M = 5.2$; $K = 13$), the epicenter of which was located in the Berezovskiy

trough (see Chapter VII). According to the existing macroseismic materials, here a quite significant force 7 area with respect to size was isolated, the basic part of which must be to the north, in the Yakut seismic zone, where the system of extended faults running from northeast to the Berezovskiy trough was isolated. The boundaries of the region before performing the special seismogeological studies must be considered quite approximate.

The broadest force 7 region encompasses part of Western Transbaykal, Central Transbaykal and a small area of Eastern Transbaykal. For strong earthquakes in the Baykal-Stanovoy zone, the tremor intensity reaches force 7 for epicentral distances to 320 km, and in individual cases to 500 and even 675 km. Thus, for example, for the earthquake of 1 February 1725 [sic] the center of which is most probably located in the Ukokan seismically active zone, in Chita (the epicentral distance is about 600 km), even the force 8 macroseismic effects were noted. Here, during the Muya earthquake (about 500 km) on 27 June 1957, numerous cases of deformations of the structures corresponding at least to force 7 macroseismic effects were noted, and for the Tas-Yuryakhskiy (675 km) on 18 January 1957, individual cases of such deformations.

The seismogeological data, the increased velocity gradients and also the relatively high degree of differentiation and contrast of the vertical neotectonic movements indicates the possibility of the occurrence in the investigated areas of Transbaykal of local force 7 earthquake centers. These include the Uletovskoye earthquake of 1912, the group of Western Transbaykal shocks of 1835) 1856 and 1935, the earthquakes of 1963, in Priargun'ye and 1965 (M = 5 1/2, in the vicinity of the Daurskiy Arch. In a number of places, seismogravitational structures are noted (for example, Tanginskaya in the border of the Ingoda Basin). With respect to the seismological data, over a significant area of Transbaykal earthquakes are possible with $K_{max} = 13$. Here the relatively high values of the velocity gradients of the vertical neotectonic movements ($2 \cdot 10^{-0}$ grad $V|_m \leq 4 \cdot 10^{-9}$ years^{-1}) serve as confirmation of the force 7 "background" seismicity, which, according to M. V. Gzovskiy, can correspond to force 7 and more rarely force 8 earthquakes.

Some expansion of the area of the force 7 regions in Transbaykal is caused, on the one hand, by the appearance of new seismostatistical materials indicating the local force 7 earthquakes (22 June 1963, M = 5.3, K = 13; 21 November 1965, M = 5 1/4, K = 14; 3 September 1970, M = 4.5, K = 13), and on the other hand, more careful analysis of the seismotectonic situation, including the velocity gradients of the latest movements.

The total area of the force 7 regions in Eastern Siberia have increased by comparison with the 1962 map and SNIP-IIA. 12-69, from 516,000 to 558,000 km^2 both as a result of a reduction in area of the force 8 regions (the Aldan Shield, the Baykal-Patomskoye Highland) and as a result of expansion of the force 6 regions (Eastern Transbaykal).

The regions with earthquake intensity of force 6 are isolated on the Siberian Platform and in the southeastern part of the Transbaykal block-wave zone (Eastern Transbaykal subzone).

On the platform the area and configuration of the force 6 seismic region are caused by the nature of propagation of the "transit" seismic oscillations from force 7 of the Baykal-Stanovoy zone of the arch-block and riftogenic movements. In Southeastern Transbaykal, on the contrary, the local center zones ($K_{max} \leq 13$) have defining significance, and the "transit" tremors play the subordinate role. As a result of the remoteness of the seismic stations from these areas, the precision of determining the epicenters of the earthquakes is insufficient to establish the relation of the earthquake centers to the specific geological structures and the morphostructures.

On the Siberian Platform side, the boundary of the force 6 zone is quite reliably substantiated by the seismostatistical material, and therefore in general is left without change by comparison with the previously existing map (Solonenko, V., 1963a, 1968a). At the same time, within the limits of the Eastern Transbaykal subzone the area of the force 6 region is increased as a result of the force 5 region isolated here. This is caused primarily by the new seismostatistical data and increased values of the velocity gradients of the vertical latest movements to $(1-2)\cdot 10^{-9}$ years^{-1}.

The most active in the territory of Eastern Transbaykal appears to be the Nerchinsko-Zavodskoy region where weak shocks have been quite frequently recorded ($K_{max} \leq 12$), and in individual years (for example, 1700, 1800, and so on), stronger earthquakes were noted according to the macroseismic data.

The latter, possibly, are connected with the "transit" tremors from the Stanovoy and the Mongolian-Okhotsk deep fracture zone. It has not been excluded that part of the weak local earthquakes here are not of tectonic origin, but landslip origin (collapses of old mines, karstic caves, and so on).

Peculiarities of the Seismic Manifestations Under Permafrost Conditions

The problem of special engineering-seismological conditions of the permafrost region has been recently stated (Solonenko, V., 1960b, 1962a), but purposeful special studies were started only in 1966 on the east bank of the Baykal rift zone where high seismic activity and complex permafrost, the thickness of which varies in short distances from 0 to 1100-1300 meters are combined (Nekrasov, et al, 1967; Nekrasov, 1970). These and subsequent studies performed under the direction of O. V. Pavlov in the Barguzin rift valley and in Transbaykal, and laboratory experiments confirmed the proposition of sharp contrast of the variation of the seismic vulnerability as a function of the permafrost conditions (Solonenko, V., et al., 1970, 1972; Pavlov, et al., 1972; Zarubin, Pavlov, 1973; Dzhurik, Leshchikov, 1973; the necessity for isolating a special engineering-seismogeocryological region in the seismic region has come. In the Northern Hemisphere[3] it occupies an area on the order of 10 million km^2, that is, about 3.5 million km^2 in the territory of the USSR, and the rest in North America (Canada, Alaska), Northeastern Greenland and on the islands in the Arctic Ocean.

[3] The Antarctic is in practice aseismic.

The effect of the seismic processes on permafrost is especially clearly and directly obvious in the seismogenic structures which during strong earthquakes experience multimeter vertical and horizontal displacements. Here old fracture zones are uncovered, and new ones occur which insure the conditions for the formation of anomalous endogenic (ascending) and exogenic (descending) thermal fluxes.

The most highly seismic permafrost region in Eurasia is the Baykal rift zone. The cryolithozone is extraordinary here. In the rift valleys there is permafrost of the "Baykal type" (Solonenko, V., 1960b): even near the southern boundary of the cryolithozone the permafrost is encountered to a depth of hundreds of meters. In the section the permafrost has two layered structure. The upper horizon is modern, predominantly insular permafrost to tens of meters thick and rarely more than 100 meters (in the northern basins according to the geological data, to 200-250 meters). The lower horizon of the permafrost is relict, syngenetic. It was formed obviously on the boundary of the Holocene where the climatic conditions promoted the formation of permafrost, and the high mobility of the earth's crust noted by seismic activation, its submersion and burial. These horizons rarely merge; as a rule, they are separated by a horizon of thawed ground from tens to hundreds of meters thick.

The Baykal type permafrost can be encountered not only in the rift zone but also in other geological structures experiencing significant plunging at the end of the Pleistocene to the beginning of the Holocene.

The dependence of the cryolithozone on the type and nature of movement of the tectonic structures has been confirmed by the geothermal observations (Demidyuk, 1968). The least value of the thermal fluxes (on the order of 300 kcal/m^2-year) and greatest thickness of the permafrost were established in the negative structures. A significantly higher thermal flux to 4,000 to 26,000 kcal/m^2-year in the positive structures and maximal, to 160,000 kcal/m^2-year and more was established with respect to the tectonic disturbance zones. Therefore in the seismically active regions, even in the frozen layer of low temperature (to -10° and lower) thick (to 1100 meters and more) permafrost, narrow, but extensive taliks [thawed ground] are encountered coordinated with the zones of tectonic disturbances and, above all, the seismogenic lineaments. They are often well deciphered with respect to vegetation, more "luxurious" and heat-loving by comparison with the vegetation of the sections alongside. However, there can be exceptions to this general rule. The inactive faults, during the course of the seismogenic movements of the earth's crust, often passively open up, and cold air can pour into them, which will promote the development of permafrost and the formation of lode ice to significant depths (on the east flank of the Baykal rift zone on the Udokan Ridge we were able to observe veins of ice to tens of centimeters thick at a depth of about 700 meters).

The permafrost essentially complicates the seismic regionalization. The proper selection of the combination of permafrost and seismic characteristics has important significance here. However, it is impossible to consider all of the variety of permafrost conditions; therefore unavoidably it is necessary to use a rough classification geocryological scheme. As the first experiment, the following versions was proposed (Solonenko, V., 1973): I--individual islands; II--insular; III--with talik islands: a) block, b) cellular or mosaic; IV--continuous; V--Baykal type.

The seismic properties of permafrost depend not only on the granulometric composition, the iciness and temperature, but also the thickness of the permafrost, the conditions of its occurrence, and so on. These relations are varied; many of them have still not been studied. In the first approximation the permafrost is divided up with respect to seismic properties into hard frozen, platy and pseudothawed and loosely frozen. The solidly frozen includes the ground, with respect to the velocities of the longitudinal seismic waves (3.5-4 km/sec and higher) and the oscillation amplitudes, similar to rock. Its temperature is below -2 to -3°. The loosely frozen and pseudothawed ground has temperatures above -1°, and the seismic properties of this ground are approximately the same as for the truly thawed ground. The platy frozen ground takes an intermediate position with respect to its seismogeocryological characteristics.

With the accumulation of factual material, it appears possible to classify the seismic permafrost-lithologic complexes. Their boundaries far from always coincide with the boundaries of the engineering-geological micro-districts. For example, in one seismic lithological-permafrost complex there can be platy frozen coarsely clastic deposits and solidly frozen fine grained soil (the velocities of the longitudinal waves, frequency-amplitude characteristics of them can be in practice identical). On making the transition to the pseudothawed or thawed state the force of the former is higher by one and the latter, by two or three; the bearing capacity and other geotechnical properties will be different.

Each of the isolated types of permafrost has its own specific engineering-seismogeocryological peculiarities.

Type I. The thickness of the permafrost in individual islands usually is less than 15 to 20 meters. The thin (first tens of meters) lenses of permafrost either have no significant effect on the amplitude level of the oscillations or during passage of the seismic waves they cause sharply expressed resonance phenomena. In the presence of water saturated soil above them capable of mud eruptions, the permafrost lenses can receive additional low frequency oscillations. The breaking up of the beds and lenses of permafrost, the settling of the individual blocks and fast degredation of it are not excluded. Therefore the construction of the capital structures on the permafrost islands without preliminary thawing of it in the seismic regions is undesirable.

Type II. Insular permafrost usually is high temperature. The soil is platy frozen or pseudothawed. By comparison with the rock and solidly frozen ground the intensity of the earthquakes rises by one to three force points. The fine-grained highly icy ground with layered and reticular structure is especially dangerous.

With a permafrost thickness on the order of 20 to 40 meters in the presence of interlayers of thawed or pseudothawed ground in it, resonance phenomena and an increase seismic danger by two to three force points are probable. In the presence of talik and pseudothawed sinks, cumulative processes are probable which can involve multiple increase in amplitudes of the oscillations and spouting of the ground in the central parts of the taliks.

Construction in this type of permafrost is also undesirable, but it can turn out to be unavoidable, for it frequently develops in the most convenient areas for development in river valleys and intermontane basins.

Type III. Permafrost with talik islands can turn out to be the most complex (especially the cellular subtype) for engineering-seismogeocryological exploration and regionalization as a result of the whimsical combination of solidly frozen, platy frozen, pseudothawed and thawed ground with sharply different seismic properties, and the morphology of the cryolithozone itself promotes broad and varied manifestation of resonance and cumulative processes[4].

For the blocks subtype permafrost the talik lineaments next to the faults are the most seismically dangerous as a result of the total increase in force points as a result of thawed ground and movements along the dislocations with a break in continuity.

The variations in the force points by comparison with the initial ones in the areas with type III permafrost can fluctuate from minus one or two to plus one to three points.

Type IV. The solid permafrost predominantly with solidly frozen ground in the foundation of the structures. When constructing while retaining the permafrost, the normative force points can be lowered by one. Usually the structures are erected on pilings with ventilated basements. However, the nature of the operation of the pilings in two (winter) or three layer medium, seismically sharply nonuniform, remains unclear. The oscillations of the foundation are realized as a result of the upper part of the ground, and with depth the amplitude of the oscillations decreases rapidly. All of this can lead to powerful shearing stresses of the pilings. However, the latter can play the role of a flexible foundation which under defined structural characteristics has a positive effect on the earthquake proofness.

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[4] This proposition has found confirmation in the instrument engineering-seismological studies performed under the direction of O. V. Pavlov. It was established that in the taliks of limited size the increase in intensity of the tremors reaches force 2.

Under structures with hot technological processes, as a rule, talik sinks occur which have a sharply negative effect on their seismic conditions.

Type V. In the areas with Baykal type permafrost, a number of specific engineering-seismogeocryological problems arise. The multilayered structure of the loose series filling the basins of the Baykal type can change the isoseismal field sharply. It is possible that this is one of the causes of significant divergence of the intensity of the tremors not only in the closely located ground, but even individual parts of the same structure which we have often encountered when investigating the consequences of strong earthquakes (Solonenko, V., 1960c).

Before the special studies of the seismic properties of the areas with permafrost of the Baykal type it is necessary to orient ourselves on the properties of the upper (modern) horizon of the permafrost considering that the lower thick (hundreds of meters) series of loose and frozen sediments extinguish the force of the seismic shocks at least by one point (Solonenko, V., 1962a; ACTIVE TECTONICS..., 1966).

In the case of seismic regionalization of the permafrost region it is necessary to compile either a complex permafrost-seismic map or superpose a geocryological map of the same scale on the basic map. The detailed seismic regionalization is most efficiently carried out on the basis of the morphostructural complex engineering-geological and geocryological regionalization.

In the case of seismic microregionalization, in accordance with the basic construction principles (while maintaining or destroying the permafrost) it is proposed that two maps be compiled: for natural conditions and for thawed ground (Solonenko, V., et al., 1970, 1972).

For regionalization of the territories of the specific structural complexes, a specialized map can be compiled considering the new postconstruction permafrost conditions or temporary maps with respect to the periods of mastery of the areas, considering that the temperature, the iciness, the ratio of the solid and liquid phases of the water, porosity and density of the soil during the course of development and during the year vary continuously reversibly and irreversibly. The seismic properties of the rock vary correspondingly: acoustic rigidity, amplitudes and periods of the oscillations of the ground, resonance and cumulative properties and also the nature of the interaction of the ground-structure system. An earthquake has an active effect on the course, especially the rate of the geocryological processes and phenomena: solifluction is accelerated, the movement of places is facilitated as a result of the mass slipping of the active layer, the established thermal regimen of the upper horizons of the permafrost is disturbed, which causes degredation of it with all of the consequences following therefrom, and it promotes the formation of avalanches. At the same time the permafrost to a significant degree determines the nature of the seismogravitational phenomena, consolidating the rock masses on the slopes and at the same time reducing the number of landslips, landslides, earth and rock avalanches, especially during earthquakes occurring during complete freezing of the active layer.

The Oymyakonskoye earthquake of 18 May 1971 (force 9, M = 7) was indicative in this respect. Its epicenter was near the pole of cold of the Northern Hemisphere. In the pleistoceism zone over an area of 3 x 6 km along the fault zone massive separations of the thawing part (about 0.3 meters) of the active layer occurred. The soil-vegetative mass in the valleys of the rivers formed mud flows up to 5 to 6 meters thick. On the general slopes (to 15°) and in the horizontal sections mass spouting of fine gravely type soil occurred (Kurushin, et al., 1972), but it was not accompanied by significant subsidence as is observed in the permafrost areas. On the whole, as a result of the permafrost, the seismogravitational phenomena during this earthquake encompassed a smaller area and had smaller dimensions than for identical earthquakes in the nonpermafrost areas.

The distribution of the tremors over the surface of the earth was also remarkable: in the area with solid permafrost the intensity of the tremor was regularly attenuated. At a distance of 250 to 350 km, it dropped to force 4 and then continued to attenuate, but at the epicentral distance of 450-500 km on reaching the insular permafrost region near the Sea of Okhotsk, the intensity of the tremor rose by 1 to 2 points. The force 4 tremor was felt on the coast of the Sea of Okhotsk at a distance of about 700 km. The relation of the tremor intensity to the type of permafrost in the given case is obvious and indisputable (Solonenko, V., 1972a).

The extended iced zones frequently are connected with fissure-stratal water of the seismogenic lineaments. In the seismogenic jointed zones in places very thick ice fields are formed--to 10 to 15 meters or more in the Syul'banskaya, China-Vakatskaya seismogenic structures of the rift system of the Stanovoy Highland (ACTIVE TECTONICS..., 1966). During the earthquake sometimes a powerful "volley" eruption of water takes place which under winter conditions leads to disastrous formations of giant ice fields. Thus, during the Gobi-Altay earthquake of 4 December 1957 (force 12, M = 8.6) an ice field more than 10 km long was formed (Solonenko, V., et al., 1960a).

In the sections with highly icy soil the earthquakes cause or activate thermokarstic processes. This is insured either as a result of the formation of fissures through which the ground water and surface water pours into the permafrost or as a result of throwing off of the active layer and uncovering the permafrost. Strong seismic shocks are not necessary for this; weak earthquake swarms can cause the same effect. For example, in 1967 in the vicinity of Leprindo Lake in the Stanovoy Highland in the epicentral area an earthquake swarm (85 shocks) of moderate intensity (K to 10-11) suddenly formed a thermokarstic mud valley 650 meters long, 10 to 15 meters wide with a depth to 6 meters and a thermokarstic sink more than 2,500 m^2 in area and 20 meters deep (in moraine).

Engineering seismogeology has been faced with complex problems in general, and especially under the conditions of permafrost (Slonenko, V., 1971, 1973). The existing methods of seismic regionalization have been developed using the materials from the seismic regions of our southern republics and foreign countries with positive geothermal regimen of the soil. The engineering-geological and instrument seismological observations give the soil parameters, characteristic of them during the investigation. During further engineering-seismogeological interpretation, the stability of these parameters is understood. Under permafrost conditions the geotechnical and seismic properties of the soil in the vicinity of the effective engineering structures change constantly. Therefore the existing development with respect to the seismic regionalization procedure, especially microregionalization are unacceptable to a significant degree in a permafrost region.

All of the growing rates of development of seismic regions in permafrost areas are bringing about a new scientific area--engineering seismogeocryology.

We have already had the opportunity to state (Solonenko, V., et al., 1971) that in the seismic areas of permafrost regions, during construction the antiseismic measures must be combined with antipermafrost measures. Therefore in order to select optimal construction sites the seismological and engineering-geocryological exploration is insufficient. A careful economic analysis is also needed. For example, construction in a force 8 region with insular permafrost (types I, II and partially V) can be more expensive than in a force 9 region but with favorable engineering-seismogeocryological conditions.

CONCLUSION

The analysis of the seismological, seismogeological, geophysical and paleoseismological data with respect to the Eastern Siberian seismic region has demonstrated that on the modern level of science, the seismic regionalization can be carried out only with complex use of the enumerated materials. Depending on the local conditions, the "weight" of certain data can be varied significantly.

In spite of the obvious achievements in seismology, seismogeology and geophysics, the seismostatistical (macroseismic and instrument) and paleoseismogeological data remain as before the only reliable data for estimating the true level of seismicity.

At the present time far from all of the territory of Eastern Siberia has been encompassed by the complex studies. The basic efforts have been aimed at studying the most seismically active parts--the Baykal rift zone--which has been investigated in quite some detail over its entire extent (about 2,000 km).

As a result of the complex studies it was discovered that the Baykal seismic belt is with respect to external signs alone part of a united Asian seismic zone entering into Eastern Siberia from Mongolia. At the southeastern projection of the Aldan Shield the seismic belt is branched: one branch is the Dzhugdzhurskaya, which runs to the Sea of Okhotsk, and the other, the Verkhoyanskaya, turns sharply to the northwest and runs to the rift system of the Arctic Ocean. This purely external factor (seismicity) has provided the basis for certain authors to see the relation of the Baykal rift zone to the world rift system. However, the individual parts of the seismic zone are connected with various types of neotectonic structures, different geophysical fields and tectonic stress fields. They have different depths and earthquake center mechanisms, that is, they are different with respect to the main tectonic-physical signs.

As is known, the effect of the tensile stresses across the structures is one of the most characteristic (if not the only) signs of typical rifts.

In this respect the Baykal rift zone is reliably isolated from the world rift system by broad fields of near horizontal compression. Moreover, it is extremely complexly constructed, both with respect to morphostructural attributes and the deep structure, and it has a mobile tectonic regimen. Over the greater part of its extent, the various morphostructures of the Baykal system are undergoing energetic modern growth in the lateral and distal directions and rearrangement.

The growth of the basins along the strike is most clearly expressed to the east of the Upper Angara Basin. Here the interrift mountain commissures are broken by the newly formed basins which finds reflection in the increased (by 3 to 5 times by comparison with the mean) seismic activity of the interbasin mountain commissures and also the eastern distal zone of the rift system. In the latter, the riftogenic processes still have almost not received morphostructural expression. With respect to the velocity gradients of the vertical tectonic movements, the geophysical and seismological calculations, K_{max} here is no more than 12 to 14 with rare recurrence rate. Actually, this is one of the most seismically dangerous sections of the rift zone with probable strong and frequent earthquakes with K to 16-17.

On the other hand, on the southwest (Eastern Sayan) flank of the rift system fading of the riftogenic processes is taking place.

Whereas in the Baykal rift zone the seismic activity is determined primarily by the development of rift basins, in the Transbaykal block-wave zone, the arched uplifts have increased seismic potential. They are weakly recompensated (see Chapter IV), and the energy of the compensation uplifts is small, insuring manifestation of rare strong (to force 8, M to 6) earthquakes. However, these earthquakes are occurring, and it is impossible not to consider them during seismic regionalization.

Between the Baykal rift and the Transbaykal block-wave zones a system of subrift structures has been isolated, the seismotectonic development of which is taking place on interaction of the movements of the riftogenic and Transbaykal types. This has also predetermined the potential seismicity of the subrift structures: the total amplitude of the vertical movements in the Neogene-Quaternary time in them is twice as high as in the Transbaykal Basins, but three to four times lower by comparison with the nearest rift valleys. The possibilities of the occurrence of earthquakes of maximum intensity (more than force 9) here obviously are lower, which was taken into account when isolating the seismic region.

The Siberian Platform, appearing to be previously seismically passive turned out to be not so lifeless. In any case, in its marginal part earthquakes are possible and sometimes occur (for example, 8 October 1974, K = 13, I_0 = force 7) which are not inferior with respect to energy to the Tashkent earthquake of 1966. This significantly expands the area of the required seismogeological-geophysical studies in Eastern Siberia (in any case when building structures of increased danger: the high-head hydroelectric power plant dams, and so on).

The quick improvement of the seismic regionalization map of Eastern Siberia has become possible as a result of the application of the paleoseismogeological method (combined with other methods of investigation). When using the popular procedures (without paleoseismogeological procedures) a long term accumulation of seismostatistical material is required. The objective analysis of the various data has demonstrated that wherever the upper level of the seismicity of specific seismogenic structures (the rift zone) has been determined by the paleoseismodislocations with certainty, the seismological and geophysical materials confirm the high values of K_{max}, A_{10} and the recurrence rates of the earthquakes.

Where there are no signs of paleoseismodislocations (the edges of the Siberian Platform), there too, according to instrument data the seismic activity is equal to or close to zero, although sometimes earthquakes occur here which in the presence of populated places would be destructive. In the areas where the paleoseismodislocations are not expressed or are absent (Transbaykal), the seismological data are unreliable. However, in such areas with time the reliability of the seismological data will be increased, at the same time as the prospects for improving the reliability of the paleoseismogeological material are problematic. This again confirms the necessity for complex studies and not confining the studies to any one method.

The paleoseismogeological data still remain the only data when discovering the evolution of seismic processes which has great significance for estimating the degree of reliability of the long-term seismic forecast according to seismological-geophysical data.

In the uninvestigated or poorly investigated regions paleoseismogeology is the only means of fast determination of the epicentral zones of strong earthquakes, their maximum intensity, the discovery of seismically active structures, and so on. In the broad investigated regions the paleoseismogeological studies can essentially supplement the seismological data. While in practice the required time of instrument observations for objective estimation of the activity, K_{max} and the seismic vulnerability is actually unknown, we can only say with certainty that the 10 year period of observations is too small for these purposes. For example, the only arch-block Udakon structure coupled with a single system of deep faults noted over the entire extent of the paleoseismodislocations of force 9-12 has A_{10} from 0.01 to 1, K_{max} from 12 to 17, seismic vulnerability of more than force 9 of 1,000 and, more rarely 50,000 (see Chapter VIII and IX). It is natural that such calculations can not be the basis for such a serious document as the State Seismic Regionalization Map.

The conclusion still remains valid that we arrived at when studying the seismicity of the rift zone of the Stanovoy Highland (ACTIVE TECTONICS..., 1966) that for quantitative estimation of the recurrence rate of the earthquakes the recurrence rate graphs can be used if they are compiled for large seismogenic structures or systems of them responsible for the preparation of strong earthquakes (an area of no less than several tens of thousands of square

kilometers). Under our conditions the recurrence rate graphs increase the number of earthquakes of force 11-12 and in this part must be corrected by the paleoseismodislocations, but they give more reliable recurrence of the force 10 shocks, the traces of which are quickly destroyed by denudation and are in part skipped over during paleoseismogeological studies.

During the course of this work, coinciding in time with the "boom" in the area of earthquake forecasting (not only location and intensity but also exact time), we have constantly followed the course of these investigations, primarily in Japan, the USA and the USSR, and we have tried to give an objective evaluation of their results insofar as possible. We have arrived at the following conclusions[1]:

1. No reliable relations have been established between the deep structure and the level of modern seismic activity of the local areas.

2. Modern movements of the earth's crust are not such a reliable index of possible seismic activity: their rates in the platform aseismic regions sometimes are 2.5-6 times higher than in the highly active seismic zones.

3. The established anamolous movements of the earth's crust which frequently are considered as predictors of earthquakes take place several hours to 40 years before strong earthquakes (the Alaskan earthquake of 27 March 1964), and probable ones, to hundreds of years.

4. The hydrogeological (including hydrochemical) changes during the course of preparation for an earthquake or the earthquake itself are observed at a distance of up to hundreds, sometimes thousands of kilometers from the epicenter and cannot be the basis for predicting the location, intensity and time of the earthquake.

5. The prediction of strong earthquakes by seismic cycles (Fedotov, 1968) begins with constancy of the seismic regimen. The facts indicate that constancy of the seismic regimen for local regions cannot be discussed, and it is only in this case that it is in practice expedient to predict earthquakes.

An unfounded amount of attention has been given to the prediction of the time of earthquakes. The index of this is the fact that in mountainous regions up to 80 to 90 percent and more of the victims and material losses are not connected with the earthquakes themselves but with the accompanying seismogravitational phenomena (landslips, landslides, earth streams and avalanches, mud flows). If in such cases the time of the earthquakes were prediced, the cities and settlements would still be lost, and the people would be killed.

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[1] From the report by V. P. Solonenko at the International Symposium on Earthquake Forecaster Research (1974).

Therefore the engineering-seismogeological forecast in mountains, especially loess regions is in practice more important than the short-term forecasting of the time of the earthquake. Under permafrost conditions (more than 50 percent of the area of the seismic regions of the USSR), the significance of the engineering-seismogeocryological forecast is still higher.

Modern knowledge of the processes leading to earthquakes do not leave room to doubt that the exact prediction of the time of an earthquake is still unattainable. At the present time seismogeologists, seismologists and geophysicists can by their collective efforts with quite high reliability forecast the location, possible intensity and approximate recurrence rate of earthquakes. "It is vitally important not to predict the exact time when a city will be destroyed but to construct it in a place and in such a way that it will not be destroyed" (Solonenko, V., 1974).

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